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EDITORIAL

AGRICULTURAL ENGINEERING : TEACHING AND INVESTIGATION AT THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

THE first of a number of reports on investigation into major problems of Colonial agriculture recommended by the Colonial Advisory Council of Agriculture, Animal Health, and Forestry, deals with Problems in the Mechanization of Native Agriculture in Tropical African Colonies*. Whether or not it be significant that this particular subject has received first attention, its importance is considerable ; but there is certainly no reason to assume that mechanization is, of itself, the prime, or even one of the prime, factors lacking in "native" systems of agriculture. The idea of mechanization, however, is likely to have a popular appeal, and, as the Authors of the Report carefully point out, "mechanization is likely to be restricted less by machinery than by agricultural, economic and social conditions". Unfortunately this is not obvious to the small farmer who usually sees in mechanization a means of providing himself with more tilled land upon which to practice his traditional

* Reviewed on page 111.

methods of cropping. As a means of agricultural improvement, mechanization alone rates " C-minus " and only commands front-rank status as one of several important methods of raising the general level of crop husbandry. Improved tillage, better weed control, higher yields and less laborious methods of crop processing can result from mechanization applied one step behind a broadening knowledge of modern crop husbandry.

With this in mind, the courses in agricultural engineering at the Imperial College of Tropical Agriculture are closely integrated with those in crop husbandry. This is particularly so in the first year of the 3-year Diploma course where care is taken to avoid any clear-cut distinction between lectures on elementary agronomy and those on farm implements. In a catch-phrase it might be said that stress is laid on the *implementation* of improved agronomy. In the third year an attempt is made to relate mechanization and land surveying to field operations, farm layout, farm management, and field practices for soil conservation. To arrange adequate practical classes with this wide scope is exceedingly difficult, but by intermingling farm walks, machine operation and field surveying, the arbitrary divisions between " subjects " in the students' minds are as far as possible broken down. Post-graduate training in mechanization is necessarily meagre and is concerned mainly with the problems that confront the Extension Officer who would introduce European, American or Australian machines into tropical peasant agriculture. For recent graduates of British or North American agricultural training centres a reorientation of view is necessary, especially as regards the objects and methods of mechanization.

Experimentation is in three broad categories, all concerned with *mechanization* as distinct from *engineering*. First, machines are observed in operation and brief reports are prepared on their performance, either in relation to their suitability for use on College land, or for general information. Copies of such reports are available to the manufacturers, but the Imperial College of Tropical Agriculture does not run an official testing service.

Secondly, particular problems in mechanization are tackled as systematically as rather limited funds and resources allow. For instance, the cultivation, harvesting and threshing of padi, by hand, animal and machine, are being compared and costed, and the mechanical performance of particular machine types in paddy land are being recorded. Similar work has been receiving considerably greater attention in Malaya, but it is considered that variation in local agricultural and economic conditions is such that duplication of this sort is not only justified but necessary.

Thirdly, some aspects of the very wide subject of mechanization for the small-holder or peasant are receiving attention. This work has started in connection with paddy cultivation and is extending to dry land food crops. Yams and pulses will receive attention.

These investigations are, in fact, performance and technique trials carried out in relation to particular crops in a particular environment. They cannot be described as research, but they have a significance which is of wide application in the tropics. Collectively they serve as a demonstration of the expensive, painstaking and lengthy series of trials, adaptations and cost-analyses which must precede successful extension work in mechanization.

Agricultural engineering is part and parcel of the two broad divisions of agricultural industry—crop husbandry and animal husbandry—and is inseparable from them. The plant can play its part in field engineering just as the animal may be supplementary, or complementary, to the tractor in field management. In teaching and in extension work, as distinct from research, the agricultural engineer in the tropics must be more agriculturist than engineer.

* * *

REPORT OF A SURVEY OF PROBLEMS IN THE MECHANIZATION OF NATIVE AGRICULTURE IN TROPICAL AFRICAN COLONIES

Colonial Advisory Council of Agriculture, Animal Health and Forestry. Publication No. 1. *H.M.S.O.* 1950. *Price :* 4s. 6d.

LITTLE that is new appears in this Report ; but here is a very interesting collation of facts and views on the application of mechanization in tropical Africa. Perhaps the most remarkable feature of the report is that although one of the three investigators fell ill after five weeks in Africa, and the others left for the United Kingdom only three weeks later, we have here a very comprehensive review of the factors affecting farming systems, the possibilities afforded by mechanization, the economic and technical limits of mechanization, the social problems and the effect of systems of land tenure and political policy. A very useful summary is given of the functions and types of various organizations for the administration of mechanization schemes.

As one would expect, in view of the transient habit of the investigators (who hopped from Uganda to Kenya, to Nyasaland, to Rhodesia, and to Nigeria within 15 days), the chapter on machine types and usage is sketchy. There are, however, excellent appendices including a memorandum on Mechanical Cultivation in Uganda by R. K. Kerkham, and some interesting notes on field sizes and farm layouts. The Report contains much that will interest every agriculturist and should be read by all who are concerned with agriculture in tropical Africa, because the influence of mechanization is not contained within the sphere of growing crops.—J.E.M.

REVIEW ARTICLES AND BOOK REVIEWS

AGRICULTURE

EAST AFRICAN AGRICULTURE

EDITED BY J. K. MATHESON AND E. W. BOVILL, *Pp.* XVI, 332, *illustrations* XXXII *plates*, 6 *maps*, *Oxford University Press*, 1950. *Price :* 25/-.

THE editors are to be congratulated upon the wealth of up-to-date information concerning agriculture and agricultural products in Kenya, Uganda, Tanganyika and Zanzibar, contained in this brief but comprehensive survey. A wide and scattered range of literature has been drawn upon and local authorities, both official and unofficial, have contributed chapters together with the editors.

The book is divided into three parts. Part One gives briefly the background and circumstances of agricultural production in East Africa—geography, land tenure, white settlement, native labour and labour welfare, soil conservation, and agricultural research. Part Two deals individually with European agricultural enterprises—an impressive list—cereals, cinchona, coffee, essential oils, fruit, groundnuts, livestock, papain, passion fruit, pyrethrum, rubber, seed-growing, sisal, sugar, tea, wattle. Part Three contains authoritative chapters on the main features of African agriculture in the four East African territories. Finally a wide range of statistics and a variety of information upon such matters as estate accounts and feeding African labour, are contained in Appendixes. Excellent photographic plates and a series of maps are provided.

As the editors state in the preface the aim is to describe East African agriculture and not to produce an agricultural text-book.

This volume, giving as it does the salient features of an incredibly vast subject, provides an excellent introduction for the newcomer to East African agriculture, and it will be dipped into with profit and widely used as a work of reference, by all concerned.—C.W.L.

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THE SCIENCE AND PRACTICE OF GRASSLAND FARMING

BY H. I. MOORE. *Thomas Nelson & Sons, Ltd.*, 1949. *Price* 8/6.

THIS up-to-date and authoritative handbook in the Nelson series of books on agriculture, lives up to its title as applied to the highly developed and specialised conditions of Britain. Concise, comprehensive and very readable, this little book is of interest to the tropical agriculturist mainly as a reminder of the vast field yet to be covered in this important subject in the tropics. Emphasis is placed throughout on grass as a crop, by far the most important crop in the United Kingdom, and upon the significance of management in maintaining the crop in a stable and high state of productivity.—C.W.L.

SOME EUROPEAN BOOKS ON TROPICAL AGRICULTURE 1946–50

By

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This article is intended as a sequel to an earlier one which appeared in *Tropical Agriculture*, Vol. XXVI, p. 126, 1949 and dealt with books published on the continent during and immediately after the war. The period now taken, 1946-50, allows some overlapping in date because certain books published in 1946-47 had not yet come to hand at the time of writing the earlier article. As before, this is only an annotated list of books which have reached one reviewer, and no guarantee can be given that some important book may not have been overlooked.

Belgium

The "Plan Decennal pour le Développement Économique et Social du Congo Belge" was published in 1949 in two volumes by Les Éditions de Visscher, Brussels. The agricultural part of the plan is covered in a hundred pages of the second volume, and with the accompanying statistical tables and maps is a useful source of reference information on present production and future prospects. It is of particular interest for comparison with the many ten-year plans for British colonies published at about the same period.

Three volumes of the "Comptes Rendus de la Conférence Africaine des Sols" held at Goma in 1948 were published as special numbers of the Bulletin Agricole du Congo Belge, 1949, but since they average nearly 1,000 pages each these may be liberally interpreted as being books. The inclusion of 180 papers by specialists from all parts of Africa south of the Sahara, together with the discussions and resolutions of the conference, makes this another indispensable reference book.

"L'Ananas" by D. Gaignaux, published by the Ministry of the Colonies in 1950, is a valuable short monograph on the pine-apple. "Tupende Kufuga Wanyama" by M. J. Celis, also published by the Ministry (2nd edition 1948) is an attractive little text-book of animal husbandry in the Congo, printed with Swahili and French versions on the same page. It should prove useful to readers of Swahili in East Africa, and a stimulus to British colonial authorities, since it fills a niche which remains empty in most British colonies.

J. Meulenbergh's "Introduction a l'Étude Pédologique des Sols du Territoire du Bas Fleuve (Congo Belge)", published by Van Campenhout, Brussels, 1949, deals mainly with local soil studies but is important for drawing attention to a phenomenon of wide interest. By contrast to the degradation

of soils and vegetation which is so widespread in Africa, the geological erosion of ancient peneplains on the lower Congo is in places leading to rejuvenation of soils and an invasion of grasslands by forest. The author points out that this also occurs in some other localities in the Belgian Congo, and he may stimulate others to look for and report it elsewhere in Africa.

The so-called "corridor settlements" in the Belgian Congo have attracted much attention from British colonial agriculturists. An excellent account of their development is now available in Prof. Malengreau's "Vers un Paysannat Indigène : Les Lotissements Agricoles au Congo Belge", a small book of 92 pages published by Van Campenhout, Brussels, 1949. This deals however in greater detail with the social than with the agricultural problems involved.

France

An addition has been made to that admirable little series "Que Sais-je ?," published by Presses Universitaires de France, by A. Chevalier and A. Angladette's "Le Riz" (1948). It is most useful to have an up-to-date treatment of this crop, based largely on French experience in Indo-China.

"L'Oeuvre des Pastoriens en Afrique Noire" by C. Mathis (Presses Universitaires de France), 1946, is a record of the work of the Pasteur Institute in French West Africa. Summaries of veterinary work undertaken are given on pages 498-560, with useful bibliographies. "Le Soya" by C. Schad, R. Mayer, and P. Hugues (Imprimerie Nationale, 1947) is a study of the classification and performance of soya varieties in France itself, but will be of interest to specialists in this crop in all countries.

"Sansanding—Les Irrigations du Niger" by G. Spitz (Société d'Éditions Géographiques, Maritimes, et Coloniales, 1949) deserves to be widely read. It makes available concise information on the French Niger irrigation scheme which has previously been hard to obtain. This project resembles the groundnut scheme in that it started with a vast plan and high hopes, met with many disappointments, but is still capable of yielding important results in a modified form. There is much to be learned from a perusal of its history. Attention will also be repaid by "Office de la Recherche Scientifique Coloniale, Rapport d'Activité pour les Années 1946-7" published by the Ministry of Overseas France in 1949, for this annual report describes the origin and aims of this great research scheme. Of particular interest is the account of the founding of the Institute at Adiopodoumé in the Ivory Coast, which it is claimed will eventually perform functions analogous to those of the Imperial College of Tropical Agriculture for the British colonies.

"E. Hugot's 'La Sucrerie de Cannes' (Dunod, Paris, 1950) is the most comprehensive work on cane sugar technology which has appeared for a number of years. Running to 820 pages and 48 chapters, it deals particularly thoroughly with the theory of the processes described and with their practice by French technicians. This book should be available in libraries in all British colonies which are interested in this subject.

Portugal

A Portuguese book which again deserves a wide public is A. L. Azevedo's "O Clima de Moçambique e a Agricultura—I" (Ministry of the Colonies, 1947), which has an English summary of 6 pages. The complete work is planned for 5 volumes, of which this first one deals with the region of Lourenço Marques. Writers on the borderland of meteorology and agriculture are rare, and the author, who shows a wide acquaintance with British and American sources, brings together much material which is not readily accessible in English.

Two other interesting books may be included here, though published by the Mozambique government at Lourenço Marques. T. de Carvalho's "Relaçao Preliminar de Doenças Encontradas em Plantas e Insectos" (1948) is an annotated host list of local plant diseases illustrated by excellent photographs and drawings. L. Pereira Coutinho's "Elementos para O Estudo e Approveitamento Agricola dos "Machongos" (1948) is a study of peaty swamp soils which will primarily interest specialists; the techniques used include pot experiments with fertilizers.

Spain

A publication on Spanish Guinea is of interest as that territory is little known to British students. This is "Ensayo Geobotanico de la Guinea Continental Espanola" by Prof. E. Guinea Lopez (Direccion General de Marruecos y Colonias, Madrid, 1946). This bulky work of 388 pages deals mainly, as the title implies, with the plant geography of the territory, but includes on pages 191-216 a reprint of a lecture by Sr. Jaime Nosti on Spanish colonial agriculture."

Switzerland

One interesting publication comes from Berne. This is G. Roberty's "Les Associations Vegetales de la Vallée Moyenne du Niger" (published by Hans Huber, 1946). The attempt to classify vegetation types in the neighbourhood of the irrigation scheme with which Spitz's book deals cannot fail to be of interest to ecologists working in northern Nigeria and the Gold Coast. The bibliography is a useful guide to vegetation studies in French West Africa.

FARM MECHANIZATION IN THE TROPICS

At the first Field Day of the new farm of the Imperial College of Tropical Agriculture, held on the 17th May, 1951, the emphasis was on small and medium-sized machines for tillage. The photographs accompanying this article show some of the machinery being demonstrated and part of the large crowd which attended. The Field Day was arranged primarily for the Agricultural Society of Trinidad and Tobago and representatives of the District Societies, but many other interested spectators attended.

Most of the machinery was shown and operated by the Port-of-Spain Agencies of the major British Agricultural machinery manufacturers. The College demonstrated a number of ploughs in action, ranging from the simple Ransome "Mysore" pulled by two Zebu oxen to the Ford-Ransomes and Ferguson mounted mouldboard and disc ploughs; and the visitors were able to see recent progress made at College Farm in the mechanization of cultivations for the planting of yams.

During the afternoon Mr. C. R. Massy of Neal and Massy Engineering Co., Ltd., Port-of-Spain, formally presented to Professor C. Y. Shephard, Acting Principal of the College, a comprehensive range of Ferguson tractor equipment which has been made available conjointly by the Coventry and Detroit Companies of the Ferguson Organization to improve the facilities of the College for teaching, demonstration and experimental work.

Additions to the equipment on the Farm have similarly recently been made by the International Harvester Company, who, through H. E. Robinson & Co., Ltd., have presented a milking machine, cooler and cream separator. Associated British Oil Engines Limited, through Charles McEnearney & Co., Ltd., have made available a special instructional Petter engine for teaching purposes; and International Crushing and Grinding Equipment, Ltd., have shipped a large capacity hammer mill for the preparation of stock-feeds.

Amongst the very small tractors on the demonstration farm are a seven-horsepower two-wheel unit, the "Trusty", which has been very successfully used for shallow ploughing and cultivations; and the seven-horsepower crawler, Ransome MG5, which has been shown to exert the same useful pull as four large oxen. These units were also made available by the generosity of their makers.

The view was expressed that agricultural field days of this sort at which members of the agricultural and business communities may meet on common ground are likely to serve a useful purpose in Trinidad. The success of the day was mainly due to the whole-hearted co-operation of the machinery dealers and to the arrangements of the College Farm for the displays of implements and the accommodation of the visitors.—J.E.M.

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MECHANIZED FARMING

(*Revised Edition*). *Anglo-American Oil Co. Ltd., London*, 1950. *Price :* 8/6.

Good practical reference books are often published by commercial concerns, and this useful handbook is first-class. The contributors include S. J. Wright, Agricultural Adviser to the Ford Motor Company and formerly Director of the N. I. A. E., and W. J. West who is Head of the Scottish Agricultural Machinery Testing Station. The information is right up to date, concise and delightfully presented with good diagrams and photographs. The text covers principles of tractor design and operation ; the care, use and adjustment of implements ; dairy equipment ; horticultural equipment ; electricity ; and, of course, the correct use and storage of fuels and lubricants. This excellent book can be recommended without reservation, to all concerned with mechanization in general agriculture. It is likely to be a particularly useful book for students.—J.E.M.

I.C.T.A. FIELD DAY, 1951

Fig. 5.—The ploughing performance of the Ransomes MG5 has been shown at the Imperial College of Tropical Agriculture to be roughly equivalent to that of four oxen. Here it is seen ploughing grassland.

Fig. 6.—A Fordson Major makes light work of three furrows during the afternoon demonstration.

I.C.T.A. FIELD DAY, 1951

Fig. 7.—The Allen "Oxford" authoscythe used in young elephant grass.

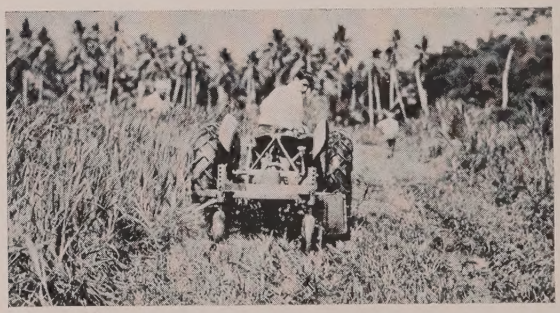

Fig. 8.—A locally built brush cutter, intended for use under tree crops and designed for attachment to the Ferguson linkage, is demonstrated in young elephant grass.

I C.T.A. FIELD DAY, 1951

(*See* article on page 116)

Fig. 1.—Part of the strong contingent of Fergusons "at the pits" before the field demonstrations.

Fig. 2.—Fordson Majors. Also a new Ford Consul saloon.

I.C.T.A. FIELD DAY, 1951

Fig. 3.—Seedbed ten inches deep formed in one operation by the Rotavator attached to the Fordson County track-layer with a Perkins P6 Diesel engine.

Fig. 4.—Grassland being ploughed with the "Trusty" tractor. This machine is under observation at the College.

PLANT AND ANIMAL NUTRITION

PROCEEDINGS OF A SPECIALIST CONFERENCE ON PLANT AND ANIMAL NUTRITION IN RELATION TO SOIL AND CLIMATIC FACTORS, AUSTRALIA, 1949

(*H.M.S.O.*, 1951. *Price :* £1 0*s.* 0*d.*)

THIS is a collection of seventy-one papers, presented at the Conference, which range over a variety of subjects. Special emphasis is laid on the climatic factor. One of the most interesting papers deals with the influence of environmental conditions on the animal and the need for a more intensive study of the climatic factors is stressed in the Resolutions of the Conference. There are, as might be expected in such a Conference held in Australia, a fair proportion of papers on the mineral requirements of plants and animals and on various pasture land problems. Many of the papers are vital but one gets the impression that the discussions which followed were somewhat arid : perhaps this is due to over condensation in the summary given by the Chairman of each sub-group.

The Recommendations and Resolutions are numerous but they have lost much of their savour with age. If a need exists for such a Conference as this, and if funds are made available for it, surely as part of its organisation provision should be made for quick publication. There is progress even in agricultural sciences and a two year lag in reporting these Proceedings is to be regretted. Much of the information would have reached its public more quickly, more cheaply and more acceptably through the medium of the usual journals.—G. AP G.

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RÔLE OF ZINC IN CROP PRODUCTION

By

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INTRODUCTION

LIKE boron, manganese and copper, zinc is an essential micro-element in plant nutrition. As early as 1869 zinc was found to be essential for some fungi (55, 56). Later investigators, however, showed that it invariably helped like other chemicals (1) to improve growth of plants in solution cultures (37, 39, 40). It was as late as 1940 when Skoog for the first time showed its essential nature in regulating growth, elongation (11) and auxin concentration in tissues. Some correlation between biological essentiality and atomic structure has also been pointed out (80). Its intimate relation with oxidation reduction,

phenomenon is also realised (82). Its absence particularly affects fruit trees and occasionally crop plants where its essentiality is tested in the traditional style by (i) producing characteristic deficiency symptoms artificially, (ii) by correcting deficiencies with zinc supply to the roots and (iii) by correcting deficiency by zinc supply to the aerial parts of the plant (7). Its requirement is so low that in nature sufficient quantities are considered to be available in many soils, yet instances are not uncommon where efficient growth and quality of plants depends on the addition of this element (8). With refined technique of micro-element nutrition its essentiality on an increasingly large number of plants is being stressed (86). Many and varied types of reactions have been associated with zinc availability and equally numerous have been the effects produced in presence or absence of this element. How and in what manner it affects growth and metabolism of plants is indicated in these pages.

Deficiency Symptoms of Zinc

Zinc deficiency produces characteristic symptoms on many plants (33, 42, 47, 48, 49, 56, 57, 75, 76, 77). Mottle leaf is considered due to lack of zinc, (58). First sign of deficiency appears as interveinal chlorosis, abnormal growth, rosetting causing little leaf or yellow disease of plants. In citrus, palisade cells are broad, transversely divided and contain few chloroplasts ; stomata are rich in fat and show elongated thin starch grains. Vacuoles often contain phenolic material and phytosterol and lecithin (59). Retarded differentiation with rhomboidal palisade cells compact mesophyll and reduced intercellular space along with hypertrophy of cells may occur (60). Mottle leaf of citrus is characterised by yellow areas between veins, newly formed leaves remain small with chlorophyll developing at the base only. Dieback may follow in extreme cases when small roots disappear first followed by larger ones (41). The disease is variously known as little leaf or frenching disease of citrus. It is considered associated with zinc availability (17, 18).

Little leaf or rosette of deciduous fruit trees is another zinc deficiency disease. In these cases, leaves turn chlorotic and show reduction in area, and are mottled and abnormal in shape. Branches dieback and fruit setting is reduced. Fruits formed are small, malformed, with brownish areas in the flesh (20). All fruit trees like apples, pears, plums, cherry, peach, apricot, almond and grape are liable to suffer from zinc deficiency (20). In apples, a rosette of small yellow leaves is formed with little or no development of lateral buds on affected branches. Fruits formed are small and misshaped, the affected branches, and sometimes the entire tree, dies (72).

In apricot and peach, the protoplast shows great affinity for dyes; chloroplasts are particularly affected. Their development is checked and marked injury may result under strong illumination (59). Occasionally plastid injury may be localised. Phenolic substances are also noted in apricot, peach and buckwheat but are absent in mustard and maize (59). In apricot meristematic cells and buds show premature vacuolisation and polarisation. Nucleii are masked by dense cytoplasm and phenolic materials. Tannins are replaced by phloroglucinol in affected cells ; but may reappear again alongside enlargement of cells and inhibition of cell division. Necrosis also results (61).

Pecan rosette is also associated with zinc deficiency. Yellow mottling of leaves and chlorosis of unfolding leaves is noted in this case. Affected leaves are reduced in size, crinkled, brittle and misshaped. Occasionally veins stand out prominently in thin reddish brown chocolate leaves. Interveinal tissues fail to develop. Smooth margined holes are scattered over the leaves. Internodes remain poor in development, branches dieback, lateral buds situated below develop and form a rosette. Fruit production is poor (28). The disease is not associated with any micro-organism or confined to any specific soil type (54) but is associated with zinc availability in some form (3, 4, 28).

In tung trees bronzing of leaves and formation of necrotic spots take place giving ragged appearance ; infection spreads to other region where new leaves become deformed, internodes fail to develop normally, twigs remain thin with bunched appearance of foliage. Injury may be local or widely spread and is aggravated by low temperature. Ultimately size of tree is affected (53).

In pinus, the first symptom is a decreased rate of growth noticeable after three months of zinc deficiency (43, 44, 74). Shoot apices exhibit a flat topped appearance. Apical buds appear bunched together while secondary needles stop growing and are short thick and stiff. Bundles do not spread open, chlorotic symptoms appear after five weeks as small yellow dots followed by browning and bronzing of leaves and conical swelling of root apices (74).

In corn, zinc reduces cobs and kernels, produces short internodes and banded chlorosis of leaves (62). White bud of maize appears within a week of emergence of the seedling from the soil; light yellow streaks between the veins of older leaves followed by necrotic spots appear. New leaves are pale yellow to white, while older ones develop brown necrotic areas which increase in size and merge with one another until the entire leaf is dead. Typical yellow interveinal striping develops as young chlorotic leaves continue to unroll. Plants show stunted growth but the root system is normal (9).

In tomato, deficient leaves exhibit dwarfing, paleness, downward curvature of leaflets, incurved laminae and necrotic spots on midribs. Palisade cells are longer while spongy tissue is more compact than normal. Chloroplasts remain small in size, low in number and show a tendency to aggregate at the lower ends. Spongy tissues show low calcium oxalate. Shrinkage, melanolic substances and reduction in size and number of plastids are noted (61).

A case of zinc toxicity has also been recorded in flax where retardation of growth, chlorosis and necrosis occurred when plants were grown in galvanized wire bird cages (51). A list of crops affected by zinc deficiency or excess appears elsewhere (81, 90).

Inter-relation between Zinc and other Elements

Zinc content of plants decreases to an almost constant value with increasing phosphate application while P content increases regularly in direct proportion to that applied. Zinc content also decreases with increasing lime application but increases regularly with addition of zinc (67). Excess also causes higher concentration of iron in chlorotic plants and affects iron utilisation in tissues (51).

Application of zinc helps chlorotic plants to regain normal green colour. A similar effect is produced by chicken manure and by alkaline peat which contain traces of zinc as impurity (9). The possibility of an interrelation between zinc deficiency and potassium in plants is also suggested. Zinc deficient plants seem to lose potassium from the roots until its content falls down to 10 to 25 per cent. of that of the aerial parts (20). The condition in the roots which permits leaching out of this potassium may favour combining with or holding of zinc in roots (20). Factors that may reduce availability of zinc in soil cause deficiency effects. Of these over cultivation, resulting in root injury combined with low nitrogen nutrition is most harmful (72).

Zinc shows favourable effects on growth and yield when applied individually or with superphosphate and copper (26). Mutual interference of response to phosphate and zinc fertilisation has also been noticed (10). In presence of superphosphate the zinc requirement increases. Addition of aluminium in presence of excessive zinc gives beneficial growth and results in a dark green colour of the leaves (32). Zinc and boron effects are also interrelated. For example in presence of excess zinc the youngest leaves of *Minium rostratum* are the first to be injured while with excess boron, leaves near the base are affected. Similarly leaf marginal cells and midribs are very sensitive to zinc and resistant to boron (13).

Zinc and Soil

The zinc deficiency problem is largely one of availability and not one of complete absence in soils. Unavailability is often associated with high pH so that the element may be held in insoluble form (70). The sensitivity to reaction manifested by certain plants is not mainly a matter of H or OH concentration but in many cases due to presence of unfavourable amounts of the element at unfavourable pH values. Thus for *Aspergillus niger*, zinc is necessary but is unavailable under alkaline conditions. Similar results have been obtained in Cytomyces. On the other hand, toxic symptoms are produced in barley, wheat, oats and rye in acid soils ; these are not due to acid alone but are largely associated with excessive quantities of zinc present (14). Zinc deficiency, salt injury and trampling and puddling effect of cattle appear inter-related in coral soils (21).

Sterilisation helps in breaking up insoluble zinc compounds and releasing them in soluble form (20). Depth of soil, prevailing temperature and amount of daylight all regulate response to zinc and development of deficiency symptoms (33, 34). Availability in general is affected by several factors among which pH, phosphates and micro-organisms are important. Raising pH reduces zinc availability in many soils (2, 30, 31, 46). Above pH 6.0 zinc content decreases. Phosphate also regulates zinc availability (10, 15, 22, 36, 50, 92) in soil in as much as plots receiving phosphate suffer from zinc deficiency (92). Increasing phosphate concentration accentuates zinc deficiency injury (22). There is little difference however, in the fixation of zinc in soil in the presence or absence of superphosphate (36). The evidence does not support the idea that phosphates fix zinc (67). Analysis of soil in one instance has shown that more than 300 lb. of zinc to the acre are

available within root zone and that even after seven years only a little more than one half pound of zinc has been found to be removed in tops, shoot and root. Even with such heavy concentrations as 116 to 136 lbs. per acre rosette formation and zinc deficiency symptoms develop in plants (2, 20). This calls forth a careful analysis of concentration relationships with the factors determining its availability and the conditions leading to its rapid absorption and translocation to the regions of active growth.

Zinc Requirement and Growth Characteristics

A number of crop plants have been shown to suffer from zinc deficiency (10, 15, 16, 30, 31). In some cases deficiency symptoms are overcome by use of zinc as a nutrient spray or by a small quantity of zinc sulphate applied to soil (16). A small amount of zinc hastens growth of rice and increases yield. Minimum harmful concentration of zinc differs from 0.5 ppm in solution cultures to 100 ppm in soil cultures (85). In maize also, growth increases in the presence of zinc (62). Zinc is equally essential for sterile cultures of fungi or water culture or soil cultures of higher plants. The so-called rosette, little leaf, mottle leaf, yellowing and bronzing in plants is cured by addition of zinc to the soil, through plant injection or through spraying the foliage of dormant wood with zinc compounds (20).

It is equally essential for vegetative and reproductive processes in peas, beans and milo. Suboptimal quantities of zinc may allow appreciable vegetative development without seed formation. A definite threshhold concentration of this element is essential for seed production. Vitality however does not vary appreciably with the vegetative vigour of plants receiving concentrations close to the threshhold values (64).

In some virgin soils zinc concentration has been found to be about 2 lb. per acre. Although yearly losses are small, it has been found necessary to apply 10 to 20 lb. of zinc sulphate per acre or to use a spray with 2 to 4 lb. of zinc sulphate per gallon of water. Even the quantity added to the soil is partly fixed by the soil and partly leached away or used by plants. Some of this is rendered unavailable by changing to the zinc-carbonate form (69). Critical analysis of the growth of peas, sunflower and radish in relation to zinc concentration has shown marked differences in the response of vegetative and reproductive functions to increasing dosages of the element. The amount of zinc stored in the seed and that supplied as impurities in the growing medium is of considerable significance (66).

The quantity of zinc absorbed by plants varies from 0.36 mgm to 8.99 mgm per kgm of fresh tissue ; the former value is obtained for endive while the latter value applies to cress (12). In pecan affected shoots contain less zinc than healthy (28). Application of zinc shows a favourable effect on growth and susceptibility to diseases (6, 23). In apple, zinc content ranges from 14 to 52 ug per gram of dried leaf tissue in one season while in another a range of 30 to 65 ug has been recorded. These variations are considered related to meteorological conditions. Zinc in concentrations below 14 ug per gram of dried leaf material invariably leads to malnutrition and appearance of deficiency symptoms (83).

In citrus, zinc increases leaf number. Dipping healthy leaf cuttings in a solution containing zinc helps rooting. Rooting in healthy leaves is affected more than rooting of mottle leaves of lemon. In diseased plants, considerable damage and death of roots is noticed (20).

Application of zinc improves growth in some plants (68). In garden peas concentrations of 0.02 to 0.20 ppm. help good growth and seed formation. In bean and milo 0.10 ppm is recommended (20). Dressings of zinc help recovery from deficiency symptoms in oranges and bronzing disease in tung. In the latter case 1/4 to 1/2 lb. of zinc sulphate per tree or spraying with a solution of 6 lb. of hydrated lime and 3 lb. of 89 per cent. zinc sulphate in 50 gallons of water containing calcium caseinate spreader has been found helpful (52). In maize 20 lb. of zinc sulphate per acre is helpful (46) in avoiding disease. Zinc sulphate at 10^{-10} to 10^{-2} milliequivalents does not cause any harm to wheat while yield of rice increases. Barley does not show any injury up to 10^{-1} while corn is also benefited for some time with 10^{-10} to 10^{-6} milliequivalents of this element in nutrient cultures (71).

Addition of 28 lb. per acre of zinc sulphate has been found in one instance to improve oat yields while straw yield is depressed (68). Similar beneficial effects of zinc have been noted on the growth of wheat, maize, lupin and peas (38), millets (5, 9, 10) and pecan (3, 4, 24, 29). Its utility to higher plants is established by many workers (33, 34, 42, 47, 48, 49, 56, 57, 75, 76, 77). Elements essential for normal development apparently occur in sufficient quantities in many soils yet the requirement of plants in changing environmental conditions may differ considerably. The importance of determining the concentrations most helpful for high yield and better quality of plant fodder is evident (8).

Zinc and Auxins

Zinc performs an important function in the maintenance of adequate auxin concentration in tissues. It is considered to be helpful for auxin synthesis and is suggested to be connected with oxidation reduction systems in plants. In its absence oxidation capacity becomes high with the result that the auxin present is readily attacked and drastically affected. If inactivation of auxin proceeds beyond a certain extent in deficient plants stem longation is retarded (73).

Terminal buds and stem sections from deficient plants as a rule yield traces or no auxin. Foliar tissues however still contain appreciable auxin though smaller in quantity than that in the control Decrease in auxin precedes appearance of visible deficiency symptoms. Deficient plants show immediate increase in auxin soon after zinc application. Zinc deficient plants inactivate indole-3-acetic acid more rapidly than controls and show a higher oxidation capacity. Application of indole-acetic acid is helpful in removing deficiency only during the early stages of zinc starvation. It is suggested that the element is principally required for maintenance of auxin in an active state while absence leads to its destruction or oxidation (73).

These results show that zinc is directly required for the synthesis of tryptophane (auxin precursor) and indirectly for synthesis of auxin (86). Availability of zinc, auxin concentration and the hydration state all appear inter-related (87).

In tomato and sunflower again addition of zinc increases auxin content even in plants in extreme stages of deficiency ; however, growth resumption is delayed. This indicates that decrease in auxin is not merely a result of decreased growth vigour (73). The free auxin content of plants fed with zinc gradually increases with age of the plants but zinc deficient plants decrease in auxin content earlier than any decline in growth (86).

Conclusion : Physiological Rôle of Zinc

Zinc is considered to bring about many vital changes in plants. In view of the fact that there are 2,000 to 3,000 times as many nitrogen atoms as zinc atoms in plant tissues, it is usually assumed that zinc is not a permanent constituent of the compounds that form the bulk of the protoplasm (88, 89).

Its presence at the centre of activities ensures good health ; its absence causes accumulation of inorganic phosphates and phenoloxidase resulting in irreversible oxidation of various cell components especially catechol (58). Accumulation of catechol aggregates under zinc deficiency in vacuoles takes place by a process of coacervation, in which dispersed particles of a colloidal system become aggregated into spherical masses surrounded by a precipitation membrane of oriented molecules of phospholipoids. These aggregates are centres of catechol derivation and catechol oxidase activity (63). With shortage of zinc oxidation reduction equilibria are disturbed, coacervation results from a gradient in the distribution of cations and correlative distribution of polyphenol oxidase. In view of differences in electrical potential between the aggregations and surrounding medium, a tendency for cations to move into coacervates takes place. This in turn influences intake of dissolved materials and causes derangement of metabolism (63). An alternative suggestion of the manner in which zinc through its effect on oxidation reduction system influences growth appears elsewhere (73).

Zinc also affects plasm viscosity (13) and is considered to catalyse essential reactions connected with oxidation processes in plants. In its absence injurious by-products are formed (19). It is not easily replaced by other elements, e.g. cadmium, magnesium, nickel, silver, iron, cobalt, copper, manganese, chromium, bromine, boron, titanium, tungsten and molybdenum (4, 19).

It is also considered to act as a catalytic agent on some essential reactions bringing about inhibition of some processes of carbohydrate transformation (20). It is a stimulant for Aspergillus rather than an essential element of plant nutrition. Direct evidence of its nutritive value however, has been put forward recently (78, 79).

Zinc is a component of a catalytic system necessary for the phosphorylation of glucose or possibly for aminoacid synthesis (35) and plays an important part in cellular oxidation (84). Deficient plants contain more

reducing sugars but less sucrose and starch than healthy (65). Cleavage of sugar is considered due to its action on zymohexase a metal protein compound containing copper and zinc. The activity of this protein is blocked by formation of a complex cystein. The blocked enzyme however is reactivated with zinc. Its presence therefore is of great importance in the sugar metabolism of the cell. It is also suggested that neutral cystein brings about an equilibrium between free and bound zinc by binding the former to sulphhydryl compounds according to the formula $\frac{\text{zinc x (cystein)n}}{\text{zinc complex}} = K$ implying thereby that the zinc-cystein complex plays an important rôle in regulating concentrations of zinc (91).

Zinc also forms compounds with various proteins of specific properties and functions. It stabilises sulphhydryl compounds such as cystein (19). Zinc is concerned with the functioning of sulphhydryl compounds such as cystein, and in their regulation of the oxidation reduction potential within cells. In deficient leaves suboxidised products of carbohydrates and proteins such as phenolic materials, phytosterol or lecithin accumulate suggesting a disturbed oxidation-reduction potential within the cells. The rôle of zinc in the maintenance of oxidation reduction potential is based upon a number of facts (27). Sulphhydryl compounds are present in all living cells and control oxidation reduction process (85). Oxidation of cystein to cystine is catalysed by metals. Finally, zinc has a specific effect in stabilising the nitroprusside colour reaction of the sulphhydryl compounds. In its absence sulphur metabolism of plants is adversely affected (81).

Manganese and iron on the one hand, and copper and zinc on the other are pairs of mutually co-ordinated catalysts for oxidation-reduction reactions. The former pair brings about reactions in which addition or removal of oxygen is involved ; the latter helps reactions which concern transference of hydrogen (81, 82).

Zinc is also stated to enter into the composition of the enzyme carbonic anhydrase which catalyses carbonic acid to carbon dioxide and water in animals (81). Its presence ensures adequate ascorbic acid content (27). It is considered to have a rôle in chlorophyll synthesis and is supposed to act as a catalytic agent in photosynthesis (25). Its absence causes reduction in photosynthesis (45). Its effects are inter-related with complex biochemical changes affecting different aspects of plant growth and metabolism, with the result that any deficiency brings about immediate effects. Its concentration in soils is fairly high yet plants growing in these soils fail to absorb this element in sufficiently high concentrations to reach the actively growing regions. Problems of zinc deficiency have therefore to be analysed from the point of view of its mobility in plant tissues and the factors affecting it more than its availability in soils under different agronomic conditions.

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TROPICAL CROPS

"LE CACAOYER" (CACAO)

By

F. THIRION

Published by authority of the Agricultural Section of the Belgian Ministry for the Colonies. Bruxelles, 1950. *Price :* 40 *francs.*

This monograph on Cacao has been compiled by F. Thirion, head of the Cocoa and Coffee section of the Agricultural Service in the Belgian Congo.

It represents a brief but highly lucid account of Cacao as a plant and as a crop of considerable commercial value.

The account commences with the botany of the plant, affinities of the species and varieties, general morphology and a description of the ecological conditions under which it thrives. The mineral nutrition of the plant is briefly dealt with—too briefly in view of the importance of nutrition in the production of high yields. The author considers that the prospective Cacao growing districts of the Belgian Congo are confined to the three districts, Mayumbe, the Central basin, and Lower Uele.

Chapter 3 is devoted to the effect of shade on the growth of Cacao. It is considered that the effect of shade is three-fold—(1) reducing the direct insolation falling on the foliage (2) avoiding sudden fluctuations in humidity and temperature of the air (3) protection of the soil against the direct effects of atmospheric conditions. It is concluded that reduction of light intensity has a beneficial effect on the growth of Cacao. No new contribution is made to the management of ground shade and permanent shade but the account gives a good summary of present day practice in the Belgian Congo. Of shade trees which have been under trial for several years, the following are considered at Yangambi :—*Maesopsis Eminii, Albizzia procera, Croton Mubango, Phyllanthus discoideus, Terminalia superba, Musanga smithii* and various species of *Macaranga.*

Propagation by vegetative methods and by seed is described and considerable attention is given to the establishment of new seedling plantations. Practical operations involved in establishment of Cacao in monoculture and in biculture with other economic crops after clean burning, after burning in strips and under forest cover are given.

Hevea and the oil palm are the two crops most frequently grown in biculture with Cacao.

Methods of maintenance of plantations including such operations as pruning, weeding and manuring are summarized. Flowering, pollination, fertilization, fruit setting and harvesting of the crop is briefly described but the author seems to have missed Humphries's important contributions to the subject of cherelle wilt.

In Chapter V attention is given to diseases and pests of Cacao. Under physiological diseases importance is placed on "Die back", "Sudden death", cherelle wilt and marginal leaf scorch. The causes given for these physiological symptoms are for the most part speculative and no new experimental evidence is submitted.

Amongst fungal diseases the following are the most important:—*Armillaria mellea* and *Rigidoporus microporus* on the roots, *Phytophthora palmivora*, *Marasmius spp.*, *Cephaleuros mycoidea* and *Diplodia theobromae* on trunk, branches, and leaves, *Phytophthora palmivora*, *Diplodia theobromae* and *Colletotrichum* on the pods. Virus diseases particularly swollen shoot have not, to date, been observed in the Belgian Congo.

The chief insect pests are considered to be *Grylloptalpa africana Tragocephala ansellii* and *Sahlbergia singuloris* although other diverse insects can do occasional damage.

The final chapter is devoted to the preparation of Cacao beans.

In conclusion, Mr. Thirion has produced a compact and lucid account of Cacao in all its aspects. It is gratifying to note the extent to which work carried out at the Imperial College of Tropical Agriculture in Trinidad has been consulted in compiling the monograph.—H. Evans.

* * *

COFFEE, TEA AND COCOA

An Economic and Political Analysis by V. D. Wickizer. *Standard University Press, Stanford, California* (*Pp.* 497. *Price :* $5.00.)

This book is a disappointment. A substantial well produced volume on the three main tropical beverages should be a welcome addition to many a library shelf, public or private. This promise in the reviewer's opinion is not fulfilled. Much of the information is up to the minute, but the great detail given to very recent fluctuations and dislocations in trade is required only by a narrow range of economists and probably not by them five years hence. When the author deals with more general aspects such as "The Evolution of the Industry" there is but a sketchy presentation of historical developments, descriptions of some planting methods, the nature of the products, &c. A hotch-potch of information unuseful to the specialist and usually uninteresting to the lay reader. Probably unintentional repetition (e.g., that tea and coffee have no nutritive value, cocoa some), is irritating. —A. L. J.

SUGAR CANE

THE 1951 NEW GUINEA EXPEDITION*

THE diversity of both wild and noble cane varieties found in the great chain of tropical islands extending out from the south-east corner of the Asian continent has led geneticists to the conclusion that this area is the centre of origin of sugar cane and although New Guinea is on the southern edge of the area, both the geographical configuration of this large island and the agricultural activities of the native inhabitants have made it a most important collecting area. The first visit was made in 1893, followed later by three other Queensland expeditions and by two American in 1928 and 1937. The latest Queensland expedition, which returned during the first week of June this year, consisted of two officers of the Queensland Bureau of Sugar Cane Experiment Stations. They were Mr. J. H. Buzacott, plant breeder, and Mr. C. G. Hughes, pathologist. Since Mr. Buzacott has had wide entomological experience and Mr. Hughes was for some time intimately associated with the cane-breeding activities of the Bureau, the personnel, although limited in numbers, was particularly well adapted for the collection and observations of *Saccharum* species from the point of view of both breeding and commercial possibilities.

Most of the time was spent in the Central Highlands, an area of mountainous country with occasional wide valleys. The base level is at an elevation of 5,500 feet and the highest mountain reaches more than 15,000 feet. Geologically the highlands are a mixture of intrusive igneous rocks, metamorphosed and unchanged sediments and old volcanic deposits so that there is a wide variation in soil fertility from district to district. The rainfall is generally more than 100 inches per annum and the streams are turbulent and swift running. The native people are excellent agriculturalists—tree culture is a regular practice—and in the more closely settled areas, which happen to be very mountainous, slopes of up to 60 degrees are cultivated without loss of soil except where a landslide occurs. The European population is still numbered in the low hundreds, and much of the area is not yet under the influence of the white man's law, i.e., is "uncontrolled" and since roads are virtually non-existent, all service is per aeroplane using small and often hazardous air-strips. The area was only discovered in the early 1930's and the 1939–1945 war seriously affected development. The extreme edge of the plateau was visited by C. G. Lennox of the Hawaiian Sugar Planters' Association in 1937, but apart from his brief visit the highlands have remained a *terra incognita* as far as the commercial cane producing countries of the world are concerned.

Food for the natives comes chiefly from the intensively cultivated gardens which although set within the one communal fence are in small sections each cultivated by individual families. The basic food is sweet potato, yam or taro depending on the district, but bananas and sugar cane are also important

* Submitted for publication by the Director, Bureau of Sugar Cane Experiment Stations, Department of Agriculture, Brisbane.

and corn, cassava, cabbages, and a wide range of minor plants add some interest to the diet. Sugar cane is sometimes grown in pure-culture stands of a few hundred separate stools but usually it is scattered through the mixture of plants in the garden. There is no particular planting season and each time a stalk is taken the upper, non-sweet portion is planted vertically in the soil. The older leaves are cut back severely but the spindle is left comparatively long. The collectors who wanted sound mature buds which would stand the transfer back to Australia, often got into arguments with the gardeners as to the planting material which should be taken. Usually the cane stalks are grown for about three years and reach a length of 20 to 22 feet of millable cane. They are tied to tall poles as they grow so that usually the trash has to be removed before the stalks can be seen. These chewing canes are generally typical nobles, of good diameter and fair brix, and, in contrast to the coastal chewing canes collected by previous expeditions, are harder than the average Queensland commercial canes. It is a tribute to the teeth of the natives that these hard-rinded varieties are so popular for chewing. The colour of the flesh varies from off-white through cream to dark brown but one variety with a red flesh was later encountered on the lowlands. The size and number of green leaves varied within wide limits and not a single arrowed stalk of a noble cane was seen anywhere in the highlands. Perhaps this was due to the more or less uniform light conditions at this low latitude and certainly indicates that, although this area yielded the collectors over 100 different noble canes, it is not the centre of origin of the species. The virtual absence of any transitional forms between the noble and the wild canes leads to the same general conclusion.

The natives are well aware of the value of sugar cane as a ready source of energy for it usually goes with them on journeys for consumption *en route* and exhausted travellers are revived with it. It is not usually eaten at meal times but serves for odd snacks and at times plays an important part in the repayment of debts of food incurred when some natural disaster has caused a shortage.

Saccharum edule which has an edible inflorescence, was found fairly widely distributed in the gardens. The aborted arrow is either roasted or steamed and is considered quite a delicacy. To European palates the mealy mass has no marked flavour but with a white sauce makes quite a pleasant vegetable.

As well as collecting noble canes for test as possible commercial canes in Queensland the expedition was also interested in the so-called wild canes. These were mostly closer to the *robustum* than the *spontaneum* types although some obvious sports were taken. Although most of the clones arrowed freely and were obviously capable of maintaining themselves in the wild state in competition with other large grasses, the conclusion was reached that with the possible exception of some parts of the eastern end of the highlands the wild canes were not native. It is apparent that the natives have moved the non-noble canes from garden to garden just as they did their chewing varieties and at the time of the expedition a *robustum* new to the Highlands was exciting considerable interest as an improvement on those already

available. It was a *robustum*-type cane with extremely large stalks and, to the surprise of the collectors, was found to have a refractometer brix of 13 despite a very hard rind and pithy interior. It was given the number 51 N.G. 91 and has at time of writing germinated in Queensland. The natives use the hard-rinded, non-noble canes in building the roofs of their low inconspicuous huts and, in the more civilized areas, for both the attachment of the thatch and for walls and floors of the European-type houses. In addition, in all localities where suitable timber is in short supply these canes are used for fencing the gardens against the ubiquitous pig and other digging animals. The stalks are pushed into the ground in line and bound to horizontal pieces to form a strong fence. The live buds soon shoot and within a few months a wall of cane has formed which persists in the grassland long after the garden has been abandoned.

In the great rift valley of the Markham River which is only a few hundred feet above sea level the non-noble canes are obviously much more at home. Square miles of alluvial plain are covered with a very wide range of clones. Any opinion as to their actual area of origin, however, awaits a further exploration of the lowland areas of the northern part of the island and perhaps other islands to the north and west.

On the way back from the Highlands collections were made along the coast near Lae on the Huon Gulf, on the Lae-Wau Road and at Sogeri some 20 to 30 miles from Port Moresby at an elevation of about 1,500 feet near the Laloki River on the famous Kokoda Trail. The material collected on the coast was not generally as promising on first appearances as that obtained in the Highlands but the Sogeri canes were quite impressive and some arrowing of nobles did occur there.

The insects found infesting sugar cane in New Guinea include the well-known linear bug, moth borer and beetle borer but in addition at least one leaf hopper not recorded in Queensland was found. From the pathological angle observations of interest included a widespread infection of downy mildew (*Sclerospora sacchari*) and Fiji disease, and the absence of mosaic disease from the Highlands. Separate reports on the insects and diseases found in New Guinea are to be published shortly by the Bureau.

The aeroplane provided this expedition with advantages not enjoyed by any previous one : Firstly, the personnel were able to move quickly from one area to another but most importantly the setts collected could be forwarded to Queensland by air and planted within a few days of being cut from the native garden. This rapid transport posed problems of quarantine but it is felt that the methods employed overcame these satisfactorily. The freshly cut setts were packed in pliofilm transparent rubber bags containing a small amount of DDT. They were sealed securely with plastic sealing tape and consigned as soon as possible. On arrival in Brisbane the bags were carefully examined before opening for any living insects. As it happens none were found. The bags were then opened and the setts treated in a solution containing 0.015 per cent. mercury in an organic form at 52 °C. for 20 minutes. Soon afterwards they were planted in a plot of loose friable

soil in an area near Brisbane well isolated from commercial cane. As a further safeguard it is planned to spray the shoots with an insecticide and a fungicide from time to time to kill any insects and prevent the transmission of any disease which might appear. It was obviously impossible to provide quarantine house facilities for such a bulk of cane plants and the open quarantine was the only alternative. The canes will be grown there for at least one year before being propagated for testing or use in the breeding programme.

* * *

APPARATUS NOTE

A CHEAP HOME-MADE DESICCATOR

THE ordinary glass laboratory desiccator is heavy, breakable, awkwardly shaped for storage and handling, and very expensive. A cheap and efficient substitute has proved sufficiently successful to be worth a brief description. Good quality biscuit or sweet tins of roughly cubical shape are used. Seams are soldered up if there is any doubt about airtightness, and the tin is given an external coat of bitumastic or other suitable anti-corrosive paint. A jar of dry calcium chloride is placed inside, its top protected with a piece of wire gauze. The material to be stored is inserted and the lid sealed down with a piece of adhesive tape. Probably the adhesive tape would be unnecessary if the lid fitted very accurately.

This type of desiccator has proved entirely satisfactory for the storage of banana seeds and would doubtless be satisfactory also for all the other purposes for which a desiccator is necessary in the wet tropics—e.g., storage of cameras, films, plates and optical equipment. It has the advantage that it is light, unbreakable, well adapted to stacking on shelves and that it costs virtually nothing.—N. W. Simmonds.

PLANT PESTS AND DISEASES

VIRUS RESEARCH AT THE WEST AFRICAN CACAO RESEARCH INSTITUTE, TAFO, GOLD COAST

By

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The West African virus diseases of cacao and their vectors have been investigated since 1945 by a team of three pathologists, J. McA. Todd and N. F. Robertson and the writer, and one entomologist, A. H. Strickland. The work done previously by H. E. Box, G. S. Cotterell, S. H. Crowdy and the writer, which formed a basis for this work, has been reviewed already (Posnette, 1945, 1947) and this paper discusses some of the subsequent findings.

Owing to the seriousness of the disease and the critical position of the cacao industry in West Africa, research has been concentrated on facets of the problem with direct applications to control measures—latent infection, wild host plants of the virus, virus-vector relationships, the ecology of the vectors, and resistance. Reference to the 1944-45 Annual Report of the West African Cacao Research Institute will reveal that practically nothing was then known about these factors ; it is impossible to condense all that is known today into a single paper for this congress and do justice to the details of the research and the techniques employed. In this paper, a review of the salient facts will be given, followed by a discussion of the problem of control in the light of this new knowledge.

Nomenclature and Classification

The diseases grouped under the name swollen-shoot are caused by a large number of viruses, some of which are certainly related strains while others are probably unrelated. This statement is based on the results of cross-protection experiments in which certain viruses have always protected cacao seedlings against graft-inoculation with certain others, although no such antagonism occurs between the majority of the cacao viruses. Serological work has not been attempted, partly because of the failure of inoculations with extracted sap (perhaps due to virus inactivation by liberated tannins) and partly because other lines of work seemed more urgent. Neither host range nor specificity of vectors has yet helped appreciably with the classification of these viruses since, with three exceptions, those that have been investigated have the same vectors and host plants.

For the present, we are referring all the West African cacao viruses to *Theobroma virus* 1 with letters to differentiate those which have been most closely studied, and place names (type locality) for the remainder (Posnette 1947.) This system is convenient in use but unsatisfactory in that it gives the incorrect impression that all the viruses are closely related ; we hope soon to be able to attempt a more logical classification.

Symptoms

The swellings from which the name swollen-shoot is derived, although very prominent with some viruses, are of little diagnostic value. Some viruses never induce swellings while others are inconsistent even when clonal test plants are used.

The viruses with which we have worked are distinguished on leaf symptoms. Many cacao viruses can be identified by the pattern and intensity of the chlorosis, but some can be distinguished only if the sequence of symptoms is followed through the preliminary, acute and chronic phases. The fine distinction between some closely related strains depends on the degree of virulence measured by the effect on growth rate and leaf size. As a generalisation it can be said that the virulent viruses cause a chlorotic pattern of either mosaic or yellows type over most of the lamina in successive growth flushes. Milder viruses, on the other hand, produce conspicuous leaf symptoms only in the acute phase, and symptoms are inconspicuous or absent from most of the leaves formed in subsequent growth.

When virus concentration is estimated by the percentage of transmission by a standard number of insects, it is found that the intensity of leaf symptoms is related to the virus concentration. For instance, the percentage of insect transmissions obtained from leaves of plants with attenuated virus 1A in the chronic (symptomless) phase is markedly lower than during the acute phase, but with virulent virus 1A in which symptoms are recurrent, there is much less difference in transmission rate.

An intensive study of the viruses occurring sporadically in the Western Province of the Gold Coast has revealed a symptom previously unsuspected in cacao viruses. This is a cloudy yellowing which spreads progressively over the older leaves including those formed *before* the plant was infected. The symptoms previously described (Posnette 1947) have appeared only on leaves developed after infection.

A recent observation of root necrosis in infected seedlings has been investigated experimentally in collaboration with D. W. Goodall, and a reduction in the dry weight of the fine roots of infected seedlings, as compared with healthy plants, has been demonstrated. This effect on the feeding roots helps to explain the rapidity with which trees are killed by the virulent viruses whose necrotic effect on the foliage is not spectacular.

Destructive Effect

The direct effect of three viruses on the yield of mature cacao was investigated by graft-infection in a 3-acre experiment run for 4 years (Crowdy and Posnette 1947). The virulent virus 1A reduced yield 25 per cent. in the first crop after infection, 50 per cent. in the second and entirely stopped production in the third crop, by which time most of the trees were dead. Virus 1C caused a 50 per cent. decline after 3 years, while 1B gave no significant reduction in yield.

The cacao viruses have two types of spread. The first gives an apparently random scatter of discrete outbreaks consisting of single infected trees. The second is the gradual enlargement of these outbreaks by tree-to-

tree spread. As the outbreak increases in size this peripheral spread proceeds more rapidly at some places than at others, the outline of the infected area becomes irregular and the outbreak enlarges in an "amoeboid" manner. Meanwhile the formation of satellite outbreaks continues by "scatter spread".

In order to estimate the combined effect of both types of spread on mortality and yield of cacao under ordinary farm conditions, an observation plot of 8¼ acres was started in 1945 when detailed inspection revealed that 31 per cent. of the trees were infected, with virulent virus 1A predominating, and 8 per cent. were dead. After three years, 80 per cent. had become infected and 47 per cent. had died of swollen-shoot disease. The 1945 main crop amounted to 41,771 pods, that for 1946 was 33,716 pods ; for 1947 24,569 pods and for 1948, 20,048 pods.

This rate of destruction seems to be typical of the Tafo district of the Gold Coast, and provides a check on the effectiveness of control by rogueing which has been practised on 70 acres at Tafo since 1940 (Posnette 1943). Between 1940 and 1947 the number of trees which became infected and were promptly cut out amounted to 4 per cent. of the mature tree population. When an adjoining 538 acres, on which no control measures had been attempted, was treated in 1946–47 over 30 per cent. of the cacao was infected (Voelcker 1948).

Latent Infection

The latent period of about 5 months before symptoms appear on mature cacao trees makes certain that all the infected trees will seldom be removed when an outbreak is first treated by the removal of trees showing symptoms. The extent of latent infection has been estimated by coppicing all symptomless trees within 50 feet of the perimeter of each outbreak, after the removal of all trees with symptoms. It has been found that symptoms appear on the first shoots from coppiced stumps if previously infected. This method has revealed that in outbreaks consisting of between 15 and 60 visibly infected trees, an additional 30-50 per cent. may be infected but symptomless. The majority of these latent infections occurred in the first ring of trees round the perimeter, about 40 per cent. of which were infected, but occasional latent infections were discovered as far away as the fourth ring.

Severe pruning was used in an attempt to hasten the appearance of symptoms (by stimulating the production of new leaves) without coppicing. This method is useful only during the period (June-October) when little or no vegetative growth normally occurs.

Vectors

The vectors of the cacao viruses have been investigated intensively since 1945 from three different aspects :—

1. The range of species capable of transmitting the different viruses.
2. The influence of feeding time on transmitting ability.
3. The biology of the vectors with special reference to their means of dispersal and possible control measures.

1. *Vector Species*

The early reports of transmission by aphids and psyllids (Cotterell 1943) have not been confirmed, and all certain vectors belong to the family *Pseudococcidae*. A new technique using seeds as test plants has greatly simplified vector experiments (Posnette and Strickland 1948). Excluding one virus for which no vector is known, all of the 15 viruses tested are transmissable by *Pseudococcus njalensis* Laing, *Ps. citri* (Risso) and *Ps. bukobensis* Laing ; *Ferrisia virgata* (Ckll.) has transmitted all but two ; *Ps. longispinus* T-T has transmitted only the two with which *F. virgata* failed. An unidentified species of *Pseudococcus* has transmitted three out of four viruses tested so far. *Ps. brevipes* (Ckll.) and *Paraputo ritchiei* Laing have each transmitted the only virus with which they have been tested. *Phenococcus maderiensis* Green, *Ps. concavocerarii* James, *Geococcus coffeae* Green, and a *Steatococcus sp.* have failed as vectors of virus 1A.

2. *Feeding Times*

The influence of feeding times has been fully investigated for two viruses, the virulent 1A and the mild 1M. As a preliminary, the effect of the number of insects on the percentage transmission was worked out, and it was found that the percentage increases from about 10 per cent. with one insect to 98 per cent. with 30 insects per test plant, using the young leaves of recently infected seedlings as the virus source and germinating cacao beans as the test plants. There is no evidence for "mass action"—the probability of transmission using many insects together is the same as the sum for the same insects used singly.

Using ten unstarved insects (*Ps. njalensis*) per test plant, the percentage transmission increased from 1 per cent. with 1 hour on the infected plant to 50 per cent. with 10 hours infection feeding. When the insects were starved for 12 hours before the infection feed, the percentage transmission increased more rapidly with feeding time to a peak of 68 per cent. at 10 hours followed by a fall to 40 per cent. at 12 hours.

A much shorter feeding period is required on the test plant. Using 10 insects to each plant and a 24 hours infection feed, 15 per cent. transmission was obtained with 20 minutes, and a peak of 60 per cent. with 50 minutes test feeding.

When insects were starved after the infection feed, they remained fully infective up to 12 hours, after which infectivity fell off and did not persist beyond 36 hours.

This loss of virus during starvation probably accounts partly for the effectiveness of rogueing without insecticidal measures. Infected trees are cut down and moved as far as possible, usually only a few yards, from healthy trees. The virus in a mature tree is transmissible by mealybugs up to 14 days after the tree has been felled, a period which depends on how long the tissues remain succulent and which is thus influenced by humidity. Some mealybugs remain on the felled tree until starved or destroyed by predators ; many of those which migrate find their way into the leaf litter or the undergrowth and probably lose their virus by feeding before reaching cacao. Judging

from the success of rogueing in stopping the peripheral spread, very few mealybugs reach healthy cacao in an infective state. In field tests, only 1 in 500 adult vectors became established on cacao 6 feet or more away from felled trees. Cacao is usually grown with the branches of neighbouring trees touching to form an interlacing canopy in which the mealybugs can walk easily from tree to tree.

3. *The Biology of the Vectors*

The cacao viruses are the only viruses at present known with certainty to be transmitted by members of the *Pseudococcidae*, which have several characteristics unusual among virus vectors, such as comparatively sedentary habits, inability to fly (males fly but do not feed and are not vectors), obligatory ant attendance (some species only, including the chief field vector of swollen-shoot) and wide host range (108 species).

Of the coccids which attack cacao in West Africa (Strickland 1947), those which have been tested as vectors are named in the paragraph on vector species. Population studies have shown that *Ps. njalensis* is the commonest species on cacao in the heavily infected areas of the Gold Coast where it is certainly the species most concerned with the spread of swollen-shoot outbreaks. With the exception of *Ps. citri*, the other vector species are rarely found on cacao in large numbers, but many cause the occasional virus transmission from wild plants to cacao—the formation of new outbreaks—and if so would be of greater practical importance than their low density suggests.

Ps. njalensis populations at Tafo, estimated during 1947-48 by monthly counts on felled cacao trees selected at random, amounted to some 42,000 insects per acre (Strickland 1948). There were, however, large variations in population from one plot to another, besides seasonal fluctuations. Eighty-four per cent. of these insects were found in the canopy layer, most of them feeding on the younger shoots between 15 and 25 feet above the ground.

Ps. njalensis is nearly always attended by ants, some species of which build carton or mud tents over the mealybugs ; 75 per cent. of the mealybug colonies counted at Tafo were ant " tented ". Crematogasterine ants are the most avid tenders of *Ps. njalensis*, *Crematogaster striatula* Emery being the most important. There is a close symbiotic relationship between these mealybugs and attendant ants. The ants feed on the " honey dew " secreted by the mealybugs, and by so doing keep the latter free from moulds. The ants also reduce attacks by predators and parasites, protect the mealybugs from rain with their " tents ", and move the young nymphs to fresh feeding sites. There is good evidence that ants are of great importance in the establishment of new mealybug colonies, and in this sense the ants play a significant rôle in the dissemination of the virus.

The natural parasitism of *Ps. njalensis* at Tafo has been estimated at a mean of 3 per cent. At least 9 species of Encyrtid parasites are present, of which *Anagyrus pullus* Compere is the most common.

Wild Host Plants

Intensive research into the host range of cacao viruses was delayed until a reliable technique for insect transmission had been perfected. Previous attempts to transfer the virus from cacao to other plants and back to cacao by grafting succeeded only with *Theobroma bicolor* (Humb. Bonpl.).

The first indigenous plant proved to be an alternative host was *Cola chlamydantha* K. Schum. Naturally infected plants with leaf symptoms were discovered in swollen-shoot outbreaks, and the virus was transmitted from them to cacao by transferring mealybugs. The testing of *C. chlamydantha* plants in the field is facilitated by the presence of natural infestations of this vector on nearly every plant, and in surveys in the Western Province (the only region of the Gold Coast where *C. chlamydantha* occurs) over one-third of tested trees were found to be infected. Infected trees are present in forest at least a mile away from known infected cacao, and regenerating stumps, often showing mosaic, are common in cacao farms.

C. chlamydantha does not occur in the Eastern Province (Gold Coast) where swollen-shoot has caused so much devastation. A systematic search for the wild host plants in this area has been made. The first step was to find the host range of the virus by attempting to infect seedlings of indigenous trees and to transmit the virus back to cacao. Common species in the Sterculiaceae, Bombacaceae and Tiliaceae were first tested and afterwards other species, irrespective of family, which are frequently found in swollen-shoot outbreaks.

The following species can be infected and virus transmitted back to cacao :—

Adansonia digitata Linn.	Bombacaceae
Bombax buonopozense P. Beauv.	,,
Ceiba pentandra Gaertn.	,,
Sterculia rhinopetala K. Schum.	Sterculiaceae
Sterculia tragacantha Lindl.	,,
Cola cordifolia R. Br.	,,
Erythropsis barteri K. Schum.	,,

As far as the most severe virus 1A is concerned, *Ceiba* and *Cola cordifolia* seem to be the most important host plants. They grow into very large trees and consequently are difficult to test by insect transmission. Symptoms are transient, and only a low percentage of transmission from infected seedlings to cacao has been obtained. Large trees of both species are now being tested in outbreaks of swollen-shoot by felling and then transferring natural infestations of mealybugs to cacao ; twigs are artificially infested with vectors in laboratory cages and further transferences made. Natural infections of both *Ceiba* and *Cola cordifolia* have now been found.

Resistance

The selection of surviving trees in heavily infected areas resulted in a large number of clones which were tested for immunity to graft infection. Apparently healthy clones which resisted infection were later found to be immunised by prior infection with an attenuated and almost symptomless

virus strain. Further investigations have shown that virus 1A is extremely variable and that many closely related strains exist with almost identical symptoms but differing greatly in virulence. Each of these strains protects plants against subsequent infection by the others. Occasionally plants are found to contain more than one strain, presumably following almost simultaneous infection, and the occasional "recovery" of infected trees after coppicing is due to the stimulation of dormant buds infected with a mild strain.

The practicability of using the mildest of the attenuated strains to immunise trees against virulent strains is now being investigated, bearing in mind such dangers as pernicious effect on yield, additive effects of unrelated "mild" viruses, and virulent mutations.

Meanwhile experiments are in progress to find plants resistant to infection by the vector, using the wide genetical range in the new types of cacao and related species introduced in 1944 from Trinidad and Brazil. The only immunity or high degree of resistance discovered so far is in the *Herrania* group, but encouraging differences in percentage infection have been obtained among cacao types, and there is much material still to be tested.

Discussion on Control

Rogueing

To evaluate correctly the results of rogueing infected trees at Tafo, certain points must be considered. Firstly, cutting out infected trees in small outbreaks undoubtedly stops the peripheral spread. Of 341 outbreaks treated up to January, 1948, only 24 were still spreading in 1949. Secondly, control measures on the 70 acres were started when less than 500 trees were infected, or under 2 per cent. of the mature tree population (Posnette 1943). An attempt to control the disease on 20 acres, with nearly 50 per cent. infection and surrounded by diseased cacao, has partially failed. Thirdly, control by rogueing has not reduced the number of new outbreaks occurring each year on the 70 acres ; neither did the removal of infected cacao from most of the adjoining land in 1945 and 1946.

These three facts emerging from control measures taken on the Institute's cacao show clearly that control measures must be applied early to be effective in saving mature cacao, and must be continued as a permanent operation with the annual loss of trees made good by young cacao coming into bearing. The removal of wild host plants will probably reduce, if not eliminate recurrent infection ; this has yet to be put to the practical test. If the disease is not amenable to control in heavily infected areas why is cutting out contemplated or in progress on such a vast scale (40, million trees !) in the Eastern Province of the Gold Coast ?

There are two reasons :—

(*a*) Replanting with seedling cacao has been, and still is practised on devastated farms. Where the soil is suitable, the seedlings become established and many have come into bearing, but the virus spreads to them from the surviving trees, slowly at first but rapidly as the foliage of the young trees touches and forms a canopy. Experiments have proved that after the removal of all infected trees,

cacao can be replanted and brought into bearing without appreciable losses from swollen-shoot. When infection has occurred in young cacao planted after cutting out, its distribution usually shows that the virus is coming from infected cacao trees left a few yards away on adjacent land. Cutting out in heavily infected farms is done primarily to make replanting practicable or to safeguard the young cacao already planted.

(*b*) The second reason why control measures should be taken in farms already heavily infected, even if the grower does not intend to replant, is because there are no natural barriers between the farms. The area where swollen-shoot is rampant is, from the control viewpoint, one cacao plantation over some 1,000 square miles. Individual peasant ownership covers only a few acres each, but the farms are contiguous, the boundaries being marked with such shade-tolerant plants as pineapples and *Dracaena* spp. An area of a square mile, in which the overall infection is 50 per cent., will contain some farms with 90 per cent. infection and some with less than 5 per cent. To treat only those farms with less than say 20 per cent. infection and to leave the remainder would be futile.

Granted the necessity for control measures over all infected areas, can the results of recent research be used immediately to improve the efficiency of the treatment? On at least one point, the answer is "No". The opposition to the destruction of visibly infected trees is already so strong that it would be unwise at present to apply one obvious improvement. The removal of a ring of symptomless trees, in addition to those showing symptoms, from outbreaks would, by removing latent infections, reduce the number of trees to be cut out after re-inspection and bring the disease under control more rapidly.

Wild Host Eradication

Fortunately, political opposition to the destruction of wild host plants does not seem likely. Here the difficulty lies in the mechanics of killing large trees which are useless for timber and undesirable as shade trees. If the organic herbicides fail, it may prove necessary to kill them by fire at the base of the trunk. These trees are of such a size when mature that they could not be felled without seriously damaging the cacao beneath, so that their destruction will be limited to farms where cacao has been killed or cut out and where new farms are to be planted. This reservation does not apply to seedlings and saplings of these species, and a growers' campaign against these throughout the cacao area would save much cacao, effort and money later when they will have grown into mature trees.

Vector Control

Research on the vectors has indicated two main lines of attack, partly complementary—chemical control of certain ant species and biological control of mealybugs. It appears that control of the attendant ants would not only lessen the mobility of the mealybugs but might also reduce the vector

population by increasing parasitism. A technique for the control of capsids on young cacao, using DD.T. (Nicol 1948), is already established and there is evidence that extension and intensification of this treatment will reduce ant attendance or at least discourage the colonisation of new plantings. Direct chemical control of the mealybugs is also being investigated. The present low rate of parasitism may be increased by the introduction of foreign parasites of other *Pseudococcus* species. One parasite introduced from Kenya has been reared successfully on *Ps. njalensis* (Posnette & Strickland 1949) and further introductions are contemplated.

Resistance

The obvious solution to the problem, resistant varieties, is being sought but is not as attractive with a permanent crop like cacao as with a short term crop. If immune varieties of cacao can be found a new industry could be built up, but the thought of this is an admission that most of the present crop, amounting to about 200,000 tons annually will be lost. At present resistance only to virus 1A is being sought, because this is both the most virulent and the most widespread virus. The complex character of this virus, indicating a high mutation rate, suggests that resistance would not be maintained for long. It is long-range planning to consider the combination of resistance to all viruses in one variety of a crop which takes five years to come into bearing.

"Acquired immunity" by the dissemination of a mild strain of the virus which will protect plants against virulent strains, is being thoroughly investigated. Again, the multiplicity of viruses is an argument against its success. The attenuated strains of virus 1A are exceedingly mild, however, and have provided complete protection against virulent 1A in numerous experiments. Under certain circumstances where normal control measures cannot succeed, "immunisation" must be considered, but it certainly should not be practised until the effects on yield have been fully investigated. These attenuated viruses are virtually symptomless and once widely distributed they could not be controlled even if they should cause a serious reduction in yield.

Conclusion

This review has shown, I believe, that the fundamentals of swollen-shoot disease are now sufficiently well understood for us to state that it is controllable. The difficulties presented on the Gold Coast today do not arise from ignorance nor from the nature of the disease, but primarily from the enormous scale which the disease has reached. There are ancillary factors, such as the present price of cocoa which makes growers loth to have any tree destroyed which can still bear a pod ; and political influences which make any Government action suspect ; but these and other obstacles could be overcome easily if every aspect of the problem was smaller. Cacao is still the primary export crop of the Gold Coast ; the disease is present in practically all the growing areas and is rampant over hundreds of square miles ; losses and compensation to be paid run into millions of pounds sterling; some

of the wild host plants are giant forest trees ; the vectors are widespread throughout West Africa and mealybugs are notoriously difficult to control ; the only cure for diseased farms is the drastic one of cutting down infected trees, of which it is estimated there are some 40 million in the Eastern Province alone. As stated in the report of the Swollen Shoot Commission, " This is no minor foray, but a full scale invasion which has already left some of the choicest cocoa producing lands devastated and derelict ".

To bring this disease under control a counter-attack must be made on a grand scale, using to the full every scrap of scientific knowledge which can be applied. Research will proceed to fill in the gaps and provide new facts, but the imperfection of present knowledge should not delay the application of subsidiary control measures which may be complementary to the basic measure—the destruction of infected cacao trees.

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AN INTRODUCTION TO THE STUDY OF VIRUSES

By Kenneth M. Smith. *Pitman & Sons, Ltd., London*, 1950. *Pp.* 106, XVI *half-tone plates. Price :* 10*s.* 6*d.*

This little book gives an interesting and useful introductory account of virus investigations, bringing together for the first time data on viruses of bacteria, higher plants, insects, birds and mammals (including man). There is a general introduction, followed by chapters on transmission, vector relationships, representative virus diseases, purification, properties, electron microscopy, serology, and virus disease control. There are a few inaccuracies, but for most of these the author cannot be blamed, as they have arisen through continued rapid development of the subject while the book was in the press. The condensation of so much into a small and inexpensive volume inevitably led to omissions—the tropical horticulturist will probably bemoan the absence of information on tree viruses. Nevertheless, the book will be useful to workers and students in many fields ; the inclusion of information on both crop and livestock viruses should make it particularly so to general agriculturists. The plates are excellent and the printing is good.—W.T.D.

* * *

THE ASSOCIATION OF ANTS WITH APHIDS AND COCCIDS

By G. E. J. Nixon. *London, Commonwealth Institute of Entomology*, 1951. *Pp.* 36. *Price :* 5/-

Problems involving the inter-relationships of insects are always fascinating and, when they concern a group of such great economic importance as the Aphids and Coccids, merit serious consideration.

The association of ants with these insects has long attracted the attention of numerous observers, but much of what has been written has been tinged with anthropomorphism. This review attempts, most successfully, to give a broad account of the main problems while including the most divergent opinions. The apparent contradictions in the literature arise for the most part from different species of ants, and/or of Aphids or Coccids, being concerned. For it is not possible, though it has often been attempted, to make generalisations about this subject : each case must be studied independently.

Two of the principal subfamilies of ants, Dorylinae and Ponerinae, are primarily carnivorous and it is only among the Myrmecinae, Camponotinae and Dolichoderinae that species associating with Aphids and Coccids are found. The benefit derived by these ants from this association is sufficiently obvious—the anal excretion, known as honey-dew, of the Homoptera provides a nutritive and readily obtainable food. Even so, the nature of the association varies : some species of ants feed mainly if not exclusively on honey-dew while others make only casual use of it.

The benefit derived by the Aphids and Coccids is, however, often less obvious and much more varied : it ranges from a few instances in which a species is unable to survive except in association with ants, to some in which no apparent advantage is obtained, or even some degree of disadvantage.

Some species of ants are definitely hostile to the predators of the Homoptera that they attend, while others do not molest them at all. The activities of parasites are less affected by ants than those of predators, but there are a few authentic instances of ants being responsible for reducing the rate of parasitization.

Several species of ants build shelters, made of material similar to that of their nests, over the colonies of Aphids and Coccids that they visit and it seems inevitable that insects thus protected should be less subject to the attack of parasites and predators.

It is generally believed that by removing excess honey-dew, which otherwise might suffocate the insects or become a medium for the growth of deleterious fungi, ants help to maintain colonies of Homopterous insects in a healthy state. This is undoubtedly true of most associations, yet there is at least one recorded case where a mealy-bug multiplied faster when freed from the ministrations of the ant that normally attended it. It is also possible that under some circumstances ants may assist in the dissemination of entomogenous fungi and thus be deleterious to the Coccids.

Another way in which a few species of ants foster certain species of Homoptera is by transporting them to new breeding places. There are ants that remove the "winter eggs" of certain Aphids to their nests in the autumn and in the following spring colonise the young Aphids on their correct food-plant. Living Coccids are also sometimes transported by ants and new colonies started, either in a different place on the same plant or on an adjacent host plant. But it is certain that this is by no means a universal and probably not even a common occurrence.

There is, however, a very close association between ants of the subgenus *Rhizomyrma* and certain root-feeding mealy-bugs. Bunzli, in 1935, described how the virgin females of *R. paramaribensis* Borg. carry first-instar female Coccids in their jaws on their marriage flight, presumably in order to start a new colony of the mealy-bug in their nest. It may interest readers of *Tropical Agriculture* to know that there is, on the Imperial College of Tropical Agriculture savannah, a common ant of this genus (*R. rutgersi* Bunzli) which has a similar habit. The virgin females of this ant, however, carry on their nuptial flight an adult female of a root-feeding mealy-bug, which has been identified by Dr. W. J. Hall (*in litt.*) as belonging to a new genus near *Rhizoecus* Kunckel.

This is a comparatively new type of publication to be issued by the Commonwealth Institute of Entomology : similar ones have appeared during the past few years dealing with Soil Insecticides, Air Transport and Insects of Agricultural Importance, and the Fruit tree Red Spider Mite. It is to be hoped that many others, equally authoritative and as well written, will be produced in due course.

An especially valuable feature of the list of some 120 references, which might with advantage be more widely adopted, is the inclusion, wherever possible, of a reference to the relevant abstracting journal, in this case the Review of Applied Entomology.

A minor criticism is that reference to the relation of ants to other families of Homoptera (Membracidae, Psyllidae, &c.) and to the larvae of certain Lycaenid and Erycinid butterflies might perhaps have been included. A single misprint was noticed, on p. 30, *Tridomyrmex* for *Iridomyrmex*.—T.W.K.

* * *

REPORT OF THE STANDING SUB-COMMITTEE OF THE CONSULTATIVE COMMITTEE ON INSECTICIDE MATERIALS OF VEGETABLE ORIGIN ON METHODS OF ANALYSIS OF VEGETABLE INSECTICIDES ON THE WORLD-WIDE COLLABORATIVE ANALYSIS OF PYRETHRUM FLOWERS—1948–1949.

Issued by Colonial Products Advisory Bureau (Plant and Animal) London, 1950. *Price : 4s. 0d. (Mimeographed).*

THE report gives the full history of an international investigation designed to establish which of the available methods for the assay of pyrethrum flowers would be best suited to fill the need for an officially recognised procedure. The investigation, most carefully planned by the sub-committee, was carried out during 1948–49 with the collaboration of pyrethrum workers in the United States and Canada, Great Britain, Europe, Africa, India, New Zealand and South-East Asia, and comprised the analysis of two samples of pyrethrum flowers, one recently harvested and one about four years old, by each of three methods.

The three methods selected, namely the Seil method, the mercury reduction method and the Ripert method, were all revised for the purposes of this programme by experts in the field of pyrethrum analysis. The old and new samples of pyrethrum flowers were prepared for analysis and randomly sampled by the sub-committee in England. The samples, together with full details of the methods to be used and, where required, the necessary reagents for making the analyses, were then despatched to the collaborators in various parts of the world. Collaborators were required to commence their analyses at a given date-line, and to submit with the results their views on the desirability of each of the methods as regards ease of manipulation, time consumption, difficulties arising from local conditions, &c. The results were finally submitted to statistical analysis.

The broad principles underlying all three analytical methods are the same. The active constituents of pyrethrum flowers are two groups of closely related substances, pyrethrin I and pyrethrin II ; the former consists of esters of chrysanthemic acid (" chrysanthemum monocarboxylic acid ") whilst the latter consists of esters of pyrethric acid (" chrysanthemum dicarboxylic acid "). All three methods of chemical analysis used in the investigation depend upon extraction and saponification of the mixed esters and

subsequent separation and estimation of the chrysanthemic and pyrethric acids produced. In the Seil and Ripert methods, separation is accomplished by distillation in steam, which removes the volatile chrysanthemic acid from the non-volatile pyrethric acid ; the Seil procedure is to extract both acids separately after steam distillation and estimate by titration with alkali, whereas the Ripert procedure is to estimate total acids after saponification and then estimate chrysanthemic acid after steam distillation. The Ripert method also includes precautions for the removal of free non-esterified chrysanthemum acids before saponification. The mercury reduction method differs from the other two in that separation of the acids is achieved by preferential extraction of chrysanthemic acid, after saponification, with hexane, and the acid is estimated by its reducing power towards mercury salts (Denige's solution).

The outcome of the investigation was that the Ripert method has been rejected as giving less concordant results than the other two methods ; and between the two remaining methods it was not found possible to decide. What has clearly emerged, however, is that the standard error of either method is very considerable ; thus for a total pyrethrin content of between 1 and 2 per cent., a difference of 0.3 by either method would have to be regarded as not significant, and the final suggestion is that for the time being contractual procedure in buying and selling pyrethrum flowers should be modified to conform to this limit of accuracy.—J.H.W.

COMMUNICATIONS ON ORIGINAL INVESTIGATIONS

INVESTIGATIONS ON THE PROPAGATION OF CACAO

By

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Summary

The paper presents the results of an investigation of the factors involved in the rooting of cacao cuttings.

The effect of treatment with root inducing synthetic hormones has been investigated and optimum concentrations determined for stem and for leaf cuttings. The quick dip method was found to be convenient and the best treatment was a mixture in equal parts of α Naphthalene acetic acid and β Indole butyric acid at a total concentration of 8–10 mgrms per millilitre of 50 per cent. alcohol for stem cuttings and 4–5 mgrms per millilitre for single node or single leaf cuttings.

Attempts to accelerate the production of rooted cuttings by prior treatments whilst the shoots were attached to the tree were not promising but some of the factors necessary for successful rooting of marcotted shoots have been defined.

The part played by the green leaf in the rooting of cuttings was investigated by nutritional and grafting experiments. It was concluded that the function of the leaf was to provide the cutting with carbohydrates and to a lesser extent of soluble nitrogen compounds. There was no evidence that the leaf exercised a special formative effect which could not be replaced by major nutrients together with root inducing synthetic hormones.

Leaves of difficult rooting *Theobroma spp.* when grafted on *Theobroma cacao* stems were effective in producing roots on the latter. Within the I.C.S. group of *Theobroma cacao* clones differences in the ease of rooting were mainly attributable to nutritional differences. By suitable treatment in the nursery it was possible to minimize these differences.

Of the external factors, light, temperature and the air-moisture relationships of the rooting media were the most important. Optimal external conditions for rapid rooting have been determined. The merit of different rooting media has been investigated and details are given of the rooting of cacao stem and leaf cuttings in closed propagators and in outside beds under mist spray. Attention was given to the technique of hardening and new methods of hardening rooted cuttings have been worked out.

The qualities of potting mixtures were studied and a suitable formula worked out for an effective potting mixture using locally available materials. An evaluation has been made of the suitability of the methods described for the large scale commercial production of rooted cacao plants.

A method of bench grafting cacao was shown to be a useful alternative method to the usual patch-bud method.

Introduction

The technique of rooting cacao cuttings, which has been in use on a commercial scale for a considerable period, was first worked out at the Imperial College of Tropical Agriculture, Trinidad, as part of the research programme of the first Cacao Research Scheme, the botanical section of which was administered by Professor E. E. Cheesman. Most of the propagation investigations were carried out by the late E. E. Pyke (1931, 1932, 1933). Pyke established many fundamental requirements for the successful rooting of cacao cuttings of which the following are worthy of note :—

1. The presence of leaves was necessary for successful rooting but even where leaves were present no roots were produced on hardwood cuttings but only on soft or semi-soft wood material from a recently matured flush. Particularly good results were obtained from vigorous flushes which had just reached maturity on two year old trees.

2. It was necessary to place the cuttings in propagation chambers, wherein the rooting medium was a coarse sand and in which the humidity was kept at almost 100 per cent. The cuttings required exposure to a moderate light intensity whilst rooting was in progress. A suitable light intensity was provided by an overhead screen of white cloth. The glass covers of the propagating chambers were also covered with cheesecloth which was kept moist, mainly to reduce the temperature within the bins.

3. Roots began to emerge three weeks after striking the cutting : at 4–5 weeks roots averaged 2–3 inches in length. Cuttings were transplanted eight weeks after striking. Chupon cuttings required a longer period than fan cuttings for the same degree of rooting.

A large number of rooted plants from selected clones were produced during the succeeding period by the use of the propagation method worked out by Pyke.

With the advent of the root-inducing hormones a certain amount of additional work was undertaken by Cheesman and Spencer (1936) in which Hortomone A, a proprietary root inducing chemical, was found to have beneficial results. Later, Jordan (1941) made a few comparisons of other root inducing chemicals and concluded that βindolyl butyric acid gave better rooting responses than Hortomone A. Jordan also attempted to investigate quantitatively the effect of varying light intensity but with inconclusive results.

A very useful general paper on the use of growth substances in the vegetative propagation of tropical plants was published by Cooper and Stoutemyer (1945) with a view to stimulating progress in the propagation o superior yielding strains of tropical plants.

The propagation of selected cacao clones on a commercial scale was undertaken by the Trinidad Cocoa Board—a semi-official body formed for the improvement of the cocoa industry and working in close co-operation with the Trinidad Department of Agriculture, in 1944 with the establishment of the La Pastora Propagation Station and later of the sub-station at Marper.

Cacao propagation stations were later set up in other West Indian islands such as Grenada, St. Vincent, St. Lucia, Dominica and Jamaica.

No further experimental work on cacao propagation was carried out in Trinidad during the last decade.

The despatch of Trinidad selected cacao clones to Surinam stimulated investigations on propagation in this territory and Stahel (1948, 1949) has made a notable contribution to propagation methods by his development of the method of propagation from single node or single leaf cuttings.

Investigations on propagation were also instituted recently in Costa Rica (1948, 1949) under the direction of the Inter-American Institute for Cacao Research. Burchardt (1950) has also extensively applied Trinidad methods of propagation with modified and simplified procedures at the Hacienda Clementina, Ecuador.

The Present Situation with respect to Cacao Propagation

In Trinidad, it became apparent as an outcome of the early work that cacao clones differ in the ease with which they are rooted: some of the shy-rooting clones have produced few or no roots under conditions which were satisfactory for the easy rooting clones.

Difficulty of vegetative propagation has been a foremost limiting factor in the extension of plantations of some selected clones. Moreover, in the case of clones considered easy to root, results of large scale commercial production have often been greatly inferior to results obtained in small scale experimental work. Between various commercial propagating stations results have varied considerably according to the skill of, and attention to detail by, the officials directing the work.

With respect to the demand for cacao clonal material the situation has also greatly changed within recent years. The fall in cacao yields as a result of pests, diseases and physiological decline in some of the cacao producing countries has led to the desirability or even to the necessity of finding new areas for cacao plantations in addition to an extensive rehabilitation of existing cacao areas. It is no longer merely a question of producing material for the renovation of existing plantations or the normal replanting of old low-bearing plantations, but of planting up thousands of acres of new

territory. It is obviously desirable that the maximum area should be planted in high yielding clonal selections rather than in seedlings of unknown performance. To achieve this it becomes necessary to make the best use of existing nursery material, much of which is already in relatively short supply and to improve propagation technique for easy-rooting as well as for difficult-rooting clones.

It was considered, therefore, that further investigations on the problem of the vegetative propagation of cacao in all its aspects was desirable with a view to placing the technique on a more quantitative basis and, in particular, of simplifying the technique for large scale commercial propagation.

For this purpose a deeper insight into the factors involved in the rooting process was essential. A survey of the literature indicated that there were several aspects of the vegetative propagation of cacao on which information was very limited. These aspects include the following:—

1. The influence of growth substances singly and in combination with each other at various concentrations on the rooting of different clonal types.

2. The possibility or otherwise of inducing the first stages of root induction whilst the shoots are still unsevered from the trees.*

3. The part played by the leaf in rooting of cacao cuttings ; in particular to determine the relative importance of the nutritive as contrasted to the formative effects of the green leaf in the rooting process.

4. The value of grafting operations to study the efficiency of leaves of different clones in the rooting process.

5. The possibility of introducing nutritive and/or substances with formative effects into the cutting with a view to replacing or reinforcing the influence of the leaf in the rooting process.

6. Aseptic culture of stems with a view to isolating the nutritional factors involved in rooting.

7. A more detailed investigation of the influence of external factors and their interaction with each other and with the nutritional status of the cutting and the formative growth effects to which nutrients are directed.

8. The interaction of external factors with the type of cutting material and the establishment of optimum conditions for varying types of cuttings.

9. Application of the results of experimental work to large scale propagation technique.

During the course of the investigation, it became apparent that the number of factors involved in the rooting process was large and included the internal condition of the cutting as well as the maintenance of optimum external factors. Moreover, previous work had not established optimum

* Since the present work was completed an abstract of a paper by Naundorf (1950) mentions experiments carried out on this subject in Colombia.

external conditions in all cases, so that experimental investigations on one set of factors required to be repeated later owing to the discovery that one or other factor had not been optimal in the earlier experiment.

Many of the experiments carried out led to negative results ; some of the treatments significantly delayed rooting. These experiments are, nevertheless, briefly mentioned in that the results frequently provide a fuller insight into the rooting process.

Experimental Results

1. The Influence of Root Promoting Substances on the Rooting of Cacao Cuttings

(*a*) *Application by the 24 hour dip in dilute solutions*

It was established in previous work that cacao cuttings deprived of their leaves failed to root. The results on this subject, however, were for cuttings not treated with root-inducing substances. Experiments were carried out in which cuttings with attached leaves were treated with growth substances for 24 hours by the dilute solution method, the leaves being removed before planting the cuttings.

The growth substances used were Indole–3–acetic acid (13A) α naphthalene acetic acid (α NA), β Indole butyric acid (β IB) Indole–3–propionic acid (13P) and a mixture in equal parts of β Indole Butyric acid plus α naphthalene acetic acid (β IB + α NA). In addition, for each concentration of growth substance the cuttings were given two sub-treatments:

(*a*) a single oblique cut at the base of the cutting.

(*b*) wounding of the tissues by scraping the rind at the base (such wounding has frequently facilitated rooting in other plant species).

The treatments given are shown in Table I and consisted of placing the cuttings one inch deep in the solutions for 24 hours.

Table I. *Treatments with growth Substances*

Concentration in milligrams per litre.

Growth substance	5	10	20	30	40	50	60	70	80	100
I3A ...			(a) (b)			(a) (b)				(a) (b)
α NA ...	(a) (b)			(a) (b)			(a) (b)			
β IB ...	(a) (b)				(a) (b)				(a) (b)	
I3P	(a) (b)				(a) (b)				(a) (b)	
α NA + β IB ...		(a) (b)			(a) (b)			(a) (b)		(a) (b)

Controls (untreated).

Twenty leafless cuttings were planted in each treatment. Only three cuttings produced roots and these roots turned brown and sloughed off after attaining a length of one inch. In most of the cuttings the buds sprouted but gave rise to thin translucent leaves which abscissed at an early stage. The experiment was repeated with supplementary treatments expected to prolong the life of the cuttings such as immersion in 1 per cent. aretan (an organo-mercurial disinfectant) and disinfection combined with waxing with low melting point paraffin wax, but no rooting occurred.

It was thus confirmed that even treatment with root inducing substances within their optimal range did not induce rooting on leafless cacao cuttings.

The same treatments as shown in Table I were then applied to leafy cuttings. The twenty cuttings in each treatment consisted of four cuttings of each of the clones I.C.S. 21, I.C.S. 38, I.C.S. 39, I.C.S. 40 and I.C.S. 56 as there was an inadequate supply of available cuttings of any one clone.

In Table II the mean number of roots per cutting and (in parentheses) the mean length of the roots in inches, four weeks after striking, are given.

TABLE II. *Mean number and mean length of roots after treatment with root inducing substances*

Concentration in milligrams per litre

Growth substance ...	5	10	20	30	40	50	60	70	80	100
13A ...			1.5 (1½)			4.3 (3½)				9.0 (4)
α NA ...	7.0 (2)			10.4 (3½)			10.7 (3½)			
β IB ...	9.0 (5)				16.0 (4½)				20.3 (3½)	
13P ...	7.8 (2)				8.1 (3¼)				9.0 (2¼)	
α NA + β IB ...		18.2 (4½)			18.1 (3½)			25.5 (4½)		29.5 (4)
Controls untreated	6.8 2½									

All the growth substances tested caused quicker and better rooting at optimum concentration in comparison with untreated control plants.

The over-all rooting percentages for the different clones were as follows :—

I.C.S. 21	I.C.S. 38	I.C.S. 39	I.C.S. 40	I.C.S. 56
52.5	50.0	90.0	85.0	35.0

The material available for cuttings was not ideal and where the percentages are low, failure was due to loss of leaves. The causes of yellowing and loss of leaves is discussed later in this report.

Rooting occurred earlier in I.C.S. 39 and I.C.S. 40 and the cuttings would normally have been ready for potting three weeks after striking. Wounding the base of the cutting by scraping the rind was of no advantage whatsoever ; in fact rotting of the basal region occurred in some of the cuttings so treated. (Several experiments were carried out with a different method of wounding. The cuttings were split for a distance of about ½ inch from the base, the split portions being kept from closing up by inserting a short piece of twine in the slit. This type of wounding likewise had no effect on the rooting, both treated and control cuttings rooting satisfactorily. It was also found to be immaterial whether the cuttings were cut immediately below a node or in the middle of the internode—providing that drainage of the rooting medium was adequate.)

From observation of the cuttings during rooting it was established that rooting was most rapid in β IB at 80 mgrms/litre and in the mixture β IB + α NA at 70 mgrms/litre.

A further experiment on the value of root inducing substances was carried out with the clone I.C.S. 1. The treatments and the percentage rooting after three weeks are summarized in Table III.

TABLE III. *Percentage rooting of cuttings following treatment with growth substances (three weeks after striking)*

Growth substance	Concentration in milligrams per litre			
	20	40	60	80
α NA	60	60	...	65
β IB	65	60	...	80
α NA + 13A	60	80	...	80
α NA + β IB	75	85	85	100

Controls untreated 55

It was apparent that of the individual growth substances tested β IB was superior to the others, but that a mixture of β IB + α NA in equal parts appeared to be still better. In order to confirm this result a further experiment was carried out, the results of which are summarized in Table IV. 26 cuttings were planted in each treatment. The figures denoted as (*a*), (*b*) and (*c*) are number of cuttings rooted, total number of roots and total root lengths in inches respectively.

This experiment confirmed the superiority of the mixture of β IB + α NA over β IB alone. It appeared that the optimum concentration by the 24 hour immersion method was approximately 80–100 mgrms. per litre.

A further experiment to establish more closely, the optimum concentration was inconclusive. The percentage rooting is shown in Table V : 30 cuttings were set in each treatment.

TABLE IV. *Rooting data following treatment with growth substances (three weeks after striking)*

Concentration in mgrms./litre

Growth substance	60	80	100
β IB	(a) 19	(a) 21	(a) 20
	(b)159	(b)167	(b)190
	(c)136	(c)190	(c)254
	(a) 20	(a) 26	(a) 24
Mixture equal parts	(b)166	(b)173	(b)229
β IB + α NA	(c)225	(c)236	(c)291
	(a) —	(a) 19	(a) —
Mixture 3 parts	(b) —	(b)203	(b) —
β IB + 1 part α NA	(c) —	(c)258	(c) —

TABLE V. *Percentage of cuttings rooted after three weeks*

Concentrations in mgrms./litre

Growth substance	70	80	100
Mixture equal parts β IB + α NA ...	88.0	81.0	97.5
Controls planted directly ...	12.5	—	—
Controls, stood in water for 24 hours	33.3		

The apparently lower rooting in the 80 mgrms/litre treatment was associated with a generally lower rooting percentage in one bin probably caused by a suboptimal external factor. Further experiments showed that the optimum concentration by the dilute 24 hour immersion method was 100 mgrms/litre although 80 mgrms sometimes gave slightly better results. Possibly the conditions for uptake may vary slightly.

Other synthetic growth substances which were tested against the mixture of β IB + α NA included Dichlorophenoxy propionic acid (D.C.P.P.) and 2.4.5. Trichlorophenoxy acetic acid (T.C.P.A.) and mixtures containing these substances :—Ten cuttings were included in each treatment. The results are presented in Table VIA and VIB below. The figures in Table VIA denoted by (*a*) are total number of roots and (*b*) the total length of roots in inches, 24 days after striking.

TABLE VI A. *Rooting following treatment with single growth substances*

Concentration in milligrams per litre

Growth substance	0.1	0.5	2.0	5.0	10.0
D.C.P.P. ...	(a) 46 (b) 31	(a) 53 (b) 44	(a) 15 (b) 4	(a) 14 (b) 2½	8 13
T.C.P.A. ...	(a) 35 (b) 24	(a) 6 (b) 1½	(a) 10 (b) 6	(a) 4 (b) ½	(a) 0 (b) 0

TABLE VI B. *Rooting following treatment with mixtures of growth substances*

Growth substances (per litre)		No. of roots	Total length of roots (ins.)
0.1 mgrm D.C.P.P. 25 mgrms β IB 25 mgrms α NA	...	78	84
0.1 mgrm T.C.P.A. 25 mgrms β IB 25 mgrms α NA	...	106	147
0.5 mgrm D.C.P.P. 35 mgrms β IB 35 mgrms α NA	...	66	85
0.5 mgrm T.C.P.A. 35 mgrms β IB 35 mgrms α NA	...	54	65
2.0 mgrms D.C.P.P. 35 mgrms β IB 35 mgrms α NA	...	68	67
2.0 mgrms T.C.P.A. 35 mgrms β IB 35 mgrms α NA	...	10	1
30 mgrms β IB 30 mgrms α NA	...	89	121
40 mgrms β IB 40 mgrms α NA	...	96	165
50 mgrms β IB 50 mgrms α NA	...	92	174

The results show that the optimum concentration for Dichlorophenoxy propionic acid alone was about 0.5 mgrm/litre and for 2.4.5. Trichlorophenoxy acetic acid 0.1 mgrm/litre or possibly less. These substances were inferior to the mixture of β IB and α NA and produced no significant improvement in the rooting response when incorporated in mixtures of β IB + α NA.

The conclusions on application of growth substance to cacao cuttings by the dilute solution method are that the best individual substance is β indole butyric acid (also known as γ–3–indole–butyric acid) at a

concentration of 100 mgrms/litre but that a mixture in equal proportions of this substance with α Naphthalene acetic acid at a total concentration of 80–100 mgrms/litre is superior to any single substance.

(*b*) *Application of growth substances by the quick-dip method.*

The tendency in recent years has been to replace the 24 hour dip in dilute solutions by an instantaneous dip in relatively concentrated solutions of the growth substances in alcohol-water mixtures.

The latter method offers great advantages where it is not required to introduce other substances such as mineral or organic nutrients into the cuttings.

The results of an experiment designed to test the efficacy of the growth substances applied by the quick dip method are shown in Table VII.

TABLE VII. *Cuttings rooted after 24 days.* (18 *cuttings planted in each treatment*).

Growth substance	Concentration in milligrams per millilitre					
	1	2	4	6	8	10
α NA	—	6	7	—	8	—
13A	—	6	6	—	10	—
β IB	—	7	9	—	11	—
β IP	—	7	9	—	11	—
P.A. (Phenyl acetic acid) ...	—	2	4	—	6	—
α NA + 13A (in equal parts)	—	8	9	—	12	12
α NA + β IB (in equal parts)	7	8	8	17	17	12
Untreated controls	6					

In the case of mixtures, the concentration refers to that of the mixture and not to that of the individual components of the mixture. As was the case with the dilute solution method the mixture of α naphthalene acetic acid and β indole butyric acid was superior to the other treatments.

A further experiment was carried out to determine the optimum concentration of this mixture. The cuttings were taken from the clone I.C.S. 1. The results are shown in Table VIII.

TABLE VIII. *Effect of different concentrations of a mixture of* α *NA* + β *IB*

Concentration (mgrms per ml)	No. of cuttings rooted after 28 days (out of 39 planted)	Total No. of roots	Total length of roots
2	27	183	184
4	31	163	139
6	28	240	294
8	31	399	536

The maximum concentration used produced the best rooting response.

(c) *Pretreatment with Phenyl acetic acid.*

Went (1939) found that the induction of roots was sometimes accelerated by pretreatment with phenyl acetic acid followed by treatment with other effective root inducing substances. An experiment was carried out in which the cuttings were left to stand for 24 hours in a solution of phenyl acetic acid at concentrations of 50, 100 and 150 mgrms per litre and then treated by the quick dip method with a mixture of α naphthalene acetic acid and β indole butyric acid at a concentration of 8 mgrms per millilitre of 50 per cent. alcohol.

I.C.S. 1 was used for the experiment there being 10 cuttings in each treatment. The results are given in Table IX.

TABLE IX. *Rooting following pretreatment with phenyl acetic acid*

Treatments	No. of cuttings rooted (out of 10 planted)	Total length of roots (in inches)
50 mgrms P.A.	8	83
100 mgrms P.A.	8	95
150 mgrms P.A.	9	109
Controls α NA + β IB only ...	9	95

There was no indication that pretreatment with Phenyl acetic acid had any effect on subsequent rooting.

(d) *Influence of growth substances on the rooting of single leaf cuttings.*

The experiments on the use of growth substances described above were conducted with normal stem cuttings. It was considered that single leaf cuttings might require a smaller dosage in view of the shortness of the stem portion in the latter type of cutting. Stahel (1948) had used as a routine treatment, the quick dip method using β indole butyric acid at 2 mgrm. per millilitre of 60 per cent. alcohol. Experiments were carried out on the effect of the mixture of β indole butyric acid and α naphthalene acetic acid on the rooting of single leaf cuttings. Some of the results are presented in Table X. The figures refer to the percentage of cuttings which had rooted sufficiently well to be potted out after three weeks.

TABLE X. *Effect of concentration of growth substance on the rooting of single leaf cuttings*

Clone, and number of cuttings per treatment	Total concentration of α NA + β IB in mgrms/millilitre						
	0	2	4	5	6	7	8
I.C.S. 60 (30)	—	40	57	—	73	—	—
I.C.S. 60 (30)	—	47	67	—	60	—	—
I.C.S. 60 (30)	—	43	62	—	67	—	—
I.C.S. 1 (20)	—	—	85	75	85	55	—
I.C.S. 1 (20)	—	—	85	80	60	70	—
I.C.S. 1 (20)	20	30	45	—	60	—	60
I.C.S. 1 (20) Number of roots ...	—	—	149	178	136	130	
Length of roots in inches	—	—	211	252	117	146	

These experiments indicate that the optimum concentration of growth substance for the treatment of single leaf cuttings is 4–5 mgrms/millilitre, i.e., exactly a half of the optimum concentration for stem cuttings.

Evidence has accumulated from routine propagation of single leaf cuttings showing that whereas a concentration of 2 mgrms/ml may give quite good results with quick rooting clones, a concentration of 4–5 mgrms is required for difficult or slow rooting clones. For example leaf cuttings of I.C.S. 55 and I.C.S. 56 which produced few or no roots in three weeks when not treated with growth substance and produced very few roots after treatment with 2 mgrm/ml—rooted freely when treated with 5–6 mgrms/ml.

A concentration of 5 mgrms/ml. (total concentration) of a mixture of α naphthalene acetic acid and β indole butyric acid has therefore been selected for routine treatment of single leaf cuttings. No inhibition of bud growth was found to result from the use of this concentration of growth substance.

2. *The results of experiments on the possibility of initiating part or the whole of the rooting process on shoots still attached to the tree*

(*a*) The literature on the influence of plant hormone applications to growing plants contains numerous references to the induction of adventitious roots on the stems of growing plants. The writer, in experiments on weed control with synthetic hormone herbicides had frequently noted prolific root induction as a result of sub-lethal applications of these substances. Moreover, Romberg and Smith (1939) have used a technique involving the application of root inducing substances in the form of "toothpicks" impregnated with the chemicals into the roots during the transplanting of pecan trees with very beneficial results in the induction of new roots.

Experiments were accordingly carried out in which small segments of match sticks were soaked overnight in absolute alcohol containing indole–3–acetic acid and in alcohol containing β indole butyric acid. After impregnation the sticks were spread out to dry on filter paper. In the first experiment the concentration of the root inducing chemicals was 100 mgrm. per millilitre but in later experiments concentrations within the range of 10 to 20 mgrm. per millilitre were used.

Small holes into which the match sticks fitted tightly were drilled in the shoots at the point where it was desired to produce roots. Further comparisons included :

(i) The removal of the terminal bud against non-removal of the bud.

(ii) Etiolation of an area one inch long above and below the point of insertion of the impregnated stick as compared with normal exposure to light. (Etiolation was effected by wrapping grafting tape round the stem).

(iii) Ring barking the stem below the point of insertion of the stick, in combination with etiolation and non-etiolation. Several hundred shoots were treated and samples were removed and placed in the rooting media in the propagators after 1, 2, 3 and 4 weeks.

The introduction of hormone impregnated match sticks resulted in the formation of localized swellings in the stem at the point of insertion. In some cases the diameter of the stem increased 3 or 4 fold as a result of the treatment. Tissue proliferation resulted partly from cell division in the cambial and cortical tissue but chiefly from active development of tissue from the phellogen. Cracks were produced in the bark, and tissue masses in the form of broad rods or plates extended through the lenticels. Some of the applied hormone was carried into the leaves directly above and, rarely, below, the point of insertion and the higher concentrations resulted in early yellowing and senescence of the affected leaves. With the lower concentrations no leaves were affected in this manner.

There was massive callus formation in those cuttings which were ring barked below the insertion, young shoots of approximately $\frac{1}{4}$ inch in diameter produced a callus ring often one inch or more in diameter.

No roots were produced on the tree by any of the treatments and no root initials were seen in sections of the proliferating tissues. On removal of the shoots and placing them under optimum rooting conditions in the propagating chambers development of undifferentiated callus rods through the lenticels continued, the white tissue later becoming rust-coloured.

Roots were finally produced on the treated shoots but the time which elapsed before roots were formed was very considerably longer than in untreated cuttings and the roots produced were thin, weak and much branched.

Generally no roots were produced on cuttings pretreated with root-inducing substances in the field until two months after placement in the propagating bins, whereas cuttings from shoots given no pretreatment rooted in 3–4 weeks. This type of pretreatment would appear to divert some essential material into callus producing activity non-conducive to root induction and such subsequently isolated cuttings require longer in the bins—presumably until an adequate supply has been built up.

Such treated and isolated cuttings were impregnated with supplementary nutrients including sucrose, urea, potassium nitrate and sodium phosphate with and without the addition of yeast extract but addition of these nutrients did not affect the rooting response.

(*b*) *The results of spraying leafy shoots with root inducing substances prior to removal from the tree*

Further experiments were carried out in which the toothpick method of applying the root-inducing substances was replaced by the technique of spraying the leafy shoots.

The treatments consisted of sprays with 10 ppm. 25 ppm. and 50 ppm. of a mixture in equal parts of β indole butyric acid and α naphthalene acetic acid, one week, two weeks and three weeks prior to removal from the tree, in combination with ring barking versus no ring barking. Controls consisted

of a random sample of the same type of shoots which did not receive any pretreatment but which were treated at the base with the optimum dosage of β indole butyric acid plus α naphthalene acetic acid immediately before planting. The results of the pretreatments in all cases resulted in a delay in rooting as compared to the untreated controls.

(c) *Conditions affecting the marcotting of shoots on the tree*

The attempts described above to induce part or the whole of root initiation on shoots still attached to the tree were analagous to the first stages of marcotting. It was decided to complete the marcotting technique by providing a suitable medium for roots to develop.

Marcotting of cacao by the usual procedures has frequently been effected —young chupon shoots arising from the base of the tree being usually the subjects rooted.

Little would be gained by adopting this procedure for the establishment of rooted cacao plants since, in its usual form, it is considerably more time consuming and troublesome than the rooting of stem cuttings.

A modified marcotting technique was used in which small cylinders of cardboard 4″—6″ long were placed around the shoots to be rooted, filled with the rooting medium at the optimum moisture content and covered over with vinalite plastic cloth which was tied around the stem above and below the cardboard cylinder as shown in text fig. 1.

This technique had the advantage that no after care whatsoever was necessary as there was no loss of moisture through the vinalite cloth.

In so far as treatment of the stem was concerned a comparison was made of:

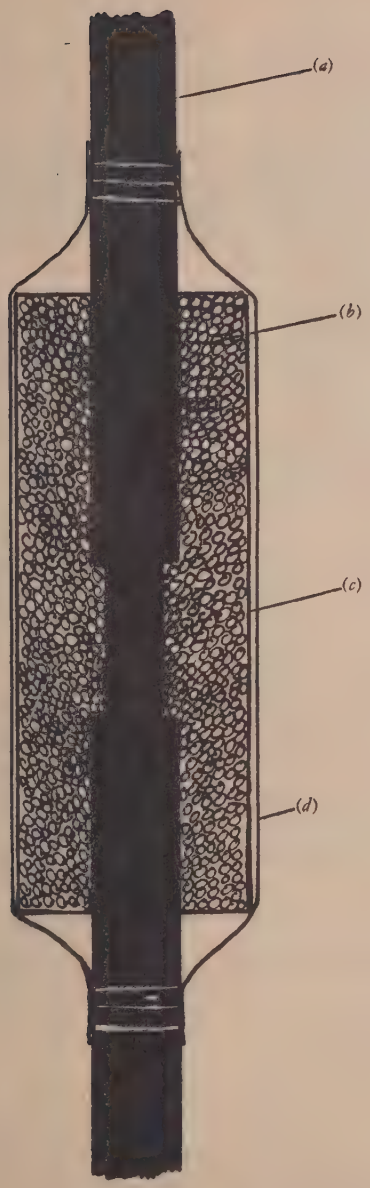
1. Scraping the bark almost down to the cambium.
2. A half ring of bark removed.
3. A three-quarter ring of bark removed.
4. Overlapping half rings of bark removed.
5. Complete ring barking.

In all cases the tissues were painted with indole butyric acid at a concentration of 2 mgrm. per millilitre. It was established that complete ringing was imperative, no rooting occurring if there was any connection through the bark.

The rooting medium and the water content of the rooting medium was also important. The best rooting media were coarsely ground charcoal and a partly rotted sawdust—moist but by no means saturated with moisture. Various grades of sand were much less effective.

The marcotting technique described above was tested out on several hundred shoots of the type usually removed as stem cuttings and not merely on strong vigorously growing chupons at the base of the tree.

Clones known to be quick rooting were successfully marcotted by this means but roots were only produced after 5–7 weeks and the percentage of shoots which rooted was low (approximately 30 per cent.). In the case of



TEXT FIG. 1. MARCOTTING METHOD
(a) Ring-Barked Shoot.
(b) Rooting Medium.
(c) Cardboard Cylinder.
(d) Vinalite Plastic Cloth.

difficult rooting I.C.S. clones—large rings of callus were produced above the ring-barked area but rooting was weak and the percentage of shoots which produced roots was low.

Several interesting facts were established from observations made on such ringed and marcotted shoots.

It was noted that ringed shoots fail to flush. In one experiment where shoots of I.C.S. 39 and I.C.S. 56 were marcotted in this fashion a general flush of the shoots on the tree commenced two weeks later. Although almost 100 per cent. of the unringed shoots flushed in both clones, not one of the ringed marcotted shoots flushed.

This fact should be of value in the determination of the influence of internal factors in the flushing of cacao. Ringed shoots not only accumulated large quantities of carbohydrate reserves but also showed symptoms of nitrogen deficiency after a few weeks. In fact such leaves formed the characteristic pattern of the high carbohydrate—low nitrate status of leaves of normal cacao trees resulting from over-exposure to sunlight and low available nitrogen. A response to nitrogen was obtained by injection of a 1 per cent. solution of urea into such leaves.

Dr. T. G. Mason informed the writer that in cotton, ringing of shoots results, in addition to accumulation of carbohydrate, in reduced stomatal opening or even closure of the stomata, reduced transpiration and marked mineral starvation. Dr. Mason suggested that the degree to which mineral starvation proceeded would be dependent on the competition from other (unringed) shoots on the tree and would therefore be subject to experimental control. An experiment was accordingly carried out in which marcots were placed on shoots of I.C.S. 1 trees in which 25 per cent., 50 per cent., 75 per cent., and 100 per cent. of the total number of shoots on the trees were ring-barked. The percentage of marcots which rooted increased with increasing percentage of ringbarked shoots as shown in Table XI.

TABLE XI

Percentage of shoots ringed	No. of marcots rooted (out of 15) after 2 months
25%	6
50%	11
75%	14
100%	12

In view of the excessive accumulation of carbohydrate in ringed shoots which may be at least partly responsible for the carbohydrate/nitrogen unbalance in the leaves of ringed shoots, experiments were carried out on the marcotting of shoots under reduced light intensity. The treatment included shoots enclosed in bags of the following materials:

(*a*) 2 layers of cheesecloth
(*b*) 1 layer of calico
(*c*) Brown paper bags painted black inside and white outside and left open at the bottom.

Controls consisted of similar shoots under natural nursery shade.

The leaves in treatment (*c*) and a considerable proportion of those in treatment (*b*) turned yellow and abscissed within 4–5 days.

The leaves survived under the cheesecloth covers. In this experiment there were no marked differences between treatment (*a*) and the untreated controls. The natural nursery shade was obviously adequate. In a further experiment the degree of shade was varied by the erection of coconut leaf screens over the experimental plants. Manipulation of the shade to approximately 1/3 of full sunlight maintained the leaves of the marcotted shoots in good condition, but the percentage of successfully rooted marcots was still affected by the proportion of ringed shoots on the tree.

(*d*) *Practicability of marcotting and definition of optimum conditions for successful marcotting*

It was not considered that marcotting even by the modified technique described above could replace rooted cuttings as a general means of cacao propagation.

It might, however, have a limited application for individual planters who wished to propagate a few dozen plants without going to the expense of installing expensive propagating equipment.

The conditions required for a reasonable percentage of successfully marcotted plants (70–80 per cent.) are as follows:—

1. The shoots to be marcotted should be relatively heavily shaded, i.e., should be exposed to about 1/3 of full sunlight.
2. A complete ring of bark must be removed and the exposed area at the top of the ring painted with indole butyric acid or other suitable root inducing substance at a concentration of 2 mgrm. per millilitre of 50 per cent. alcohol
3. At least 50 per cent. of the shoots on the tree should be marcotted or alternatively 50 per cent. of the shoots on the tree ringbarked.
4. A suitable rooting medium is composted sawdust, damp but not excessively wet placed in cardboard cylinders covered with transparent waterproof plastic cloth.
5. The roots, which are produced in 6–8 weeks, can generally be seen through the plastic and so information on the progress of rooting may be obtained without having to remove the rooting medium.
6. Shoots to be marcotted should have bark of a light brown colour, i.e., shoots in the same condition as those normally taken for stem cuttings.
7. In high winds some of the marcotted stems may snap unless supported or reinforced.
8. Vigorous chupons from the base of the tree can be marcotted without ringing other shoots on the tree.
9. The cut marcots should be placed in a shaded, moist location and watered frequently after potting out.

NOTE—A very considerable improvement in marcotting technique eliminating the deleterious aspects accompanying complete ring barking and resulting in excellent rooting in 3–4 weeks was subsequently effected. The improved method, which supersedes that described above is being published in Cacao Research Report, I.C.T.A. Trinidad, 1952, (in preparation).

3. *The part played by the green leaf in the rooting of cacao cuttings*

(*a*) Leafless cacao cuttings did not normally produce roots even under optimum conditions including suitable treatment with root inducing substances. In the case of the few cuttings which produced roots, the roots rotted after a short period. It was, however, possible to reduce the leaf area on a cutting to quite an appreciable extent without greatly affecting root formation. It is, indeed, normal practice to remove 2/3–1/2 of the total leaf surface in order to facilitate spacing the cuttings in the propagating chambers. There was, however, a limit beyond which further depletion of the leaf area caused a reduction and/or a considerable delay in the appearance of roots. This lower limit varied in different clones between 10 per cent. and 15 per cent. of the original area. Dr. E. Phillis informed the writer that, over a period, the limit below which no rooting takes place was in his experience, about 1/7 of the original leaf area.

The present writer found, however, that the minimal leaf area required for rooting varied with the environmental factors, particularly light intensity. It also depended on the weight of stem tissue supplied by the given leaf area. Thus about a quarter of one leaf would produce roots on a single leaf cutting with one inch of stem tissue attached but the same leaf area would not produce roots on a stem cutting 9–12 inches long. The most likely explanation of this fact was that the large amount of stem tissue was a liability in that its respiration requirements were quite appreciable and the balance of respiration and photosynthesis was on the debit side, whereas where the same leaf area had only to supply an inch or so of stem tissue the balance was on the credit side and rooting occurred.

By placing leafy cuttings in complete darkness, it was shown that the nutrient reserve in a cacao cutting was very low and in the absence of photosynthesis was only sufficient to supply the requirements for 5–8 days. By raising the temperature from 28°C to 32°C, starvation was markedly accelerated. There was previously no conclusive evidence that the part played by the leaf was primarily photosynthetic although the importance of the leaf in the rooting process had been fairly well established.

(*b*) *Grafting experiments*

With a view to determining whether leaves of easy rooting clones had a greater effect on rooting than those of difficult rooting clones stem cuttings of the reputedly slow rooting I.C.S. 55 and I.C.S. 56 were deprived of their leaves. Leaves of I.C.S 1, I.C.S. 60 and I.C.S. 56 were grafted on the leafless stems. This operation proved to be fairly easy if carried out late in the afternoon. The method adopted was to make a transverse cut of the bark ¾″ above and below the leaf selected for grafting with two vertical cuts so as to remove the bark from half the circumference of the shoot. By inserting sharp pressure on the petiole of the leaf the bark was loosened. The patch of bark was quickly measured on the stem on to which it was to be grafted and an equivalent piece of bark removed. The bark with attached leaf was inserted in position, tied with grafting tape and, when sufficient leaves had been grafted, the cutting was treated with root inducing substance by the quick dip method

and placed in the propagating bin. The leafless stems of I.C.S. 55 and I.C.S. 56 on to which leaves were grafted had all rooted within 5 weeks but the technique was not sufficiently refined to establish differences in the rooting efficacy of the various clones from which leaves were taken.

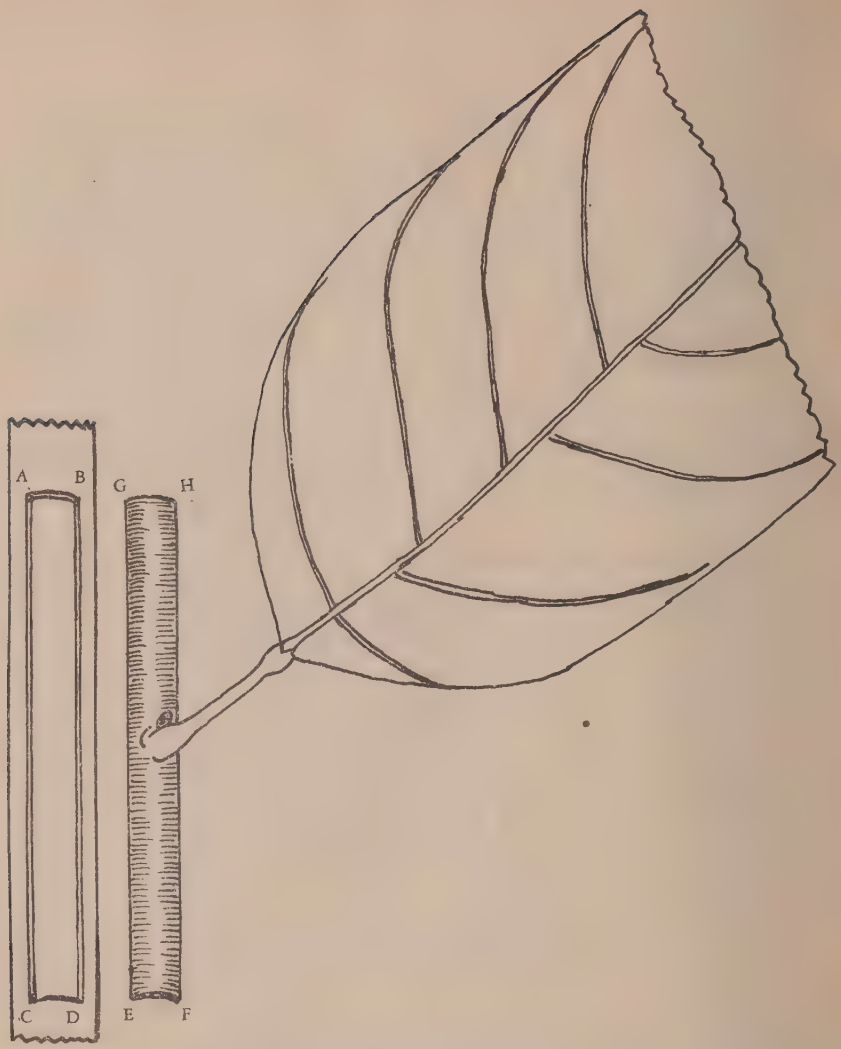
The time for roots to be produced at the base of the stem was extended by the time required for vascular connections to be formed. Such cuttings therefore, took about 5 weeks to root instead of the usual 3 weeks. Very frequently roots were produced in the moist air of the propagators from the bark bearing the leaf in the region E.F. in Text Fig. 2. The grafting of one fairly large leaf was sufficient to produce a good root system on the stem cutting but root formation was quicker when two leaves were grafted.

The effect of grafting easy rooting clones on more difficult rooting clones of the I.C.S. series was also investigated by bench grafting shoots of the former type on to shoots of the latter type. The methods used are described in a later section ; all such grafts rooted readily in 4 weeks. Both leaf-grafting and shoot-grafting methods were tested in attempts to root the difficult rooting *Theobroma spp*, *Th. bicolor*, *Th. angustifolia* and *Th. grandiflorum*. These species were far more difficult to root than *Th. cacao*.

In a later section the technique used to produce rooted plants of these species is described. With respect to the problem of leaf function in rooting it was established that the grafting of leaves of easy rooting *Theobroma cacao* clones on to the stem of the other *Theobroma spp* referred to above did not accelerate the rooting of the latter species. The grafts produced an effective union in a sufficiently high percentage to test out the function of the leaf. Roots were, in fact, produced on *Th. angustifolia* and *Th. grandiflorum* stems bearing exclusively *Theobroma cacao* leaves. The bark of the I.C.S. clones used, produced roots in the region E.F. within one month but it was only after four months or more in the propagating chambers that roots were produced at the base of the *Theobroma grandiflorum* and *Th. angustifolia* stems. No successful grafts could be made on *Th. bicolor*, although some callus was formed at the union.

Under the most optimum conditions *Th. angustifolia* rooted in 6–9 weeks and *Th. grandiflorum* in 8–12 weeks and the percentage of cuttings rooting was very low. The grafting of the leaves of easy rooting I.C.S. clones on these species therefore, in no way accelerated the rate of rooting. On the other hand, portions of bark of I.C.S. clones grafted on to the stem of leafy shoots of *Th. grandiflorum* produced roots in one month. The *Th. grandiflorum* leaves were thus quite adequate in supplying the bark of the *Th. cacao* clones with the substances necessary to produce rooting. The tentative conclusions to be drawn from these facts are that the function of the leaf is mainly to supply the major nutrients and that the condition of the stem at the site where root primordia are formed is an important factor in causing differences between easy and difficult rooting Theobroma species.

Further evidence on this subject was provided by a comparison of the time required for rooting in single node (or single leaf cuttings) with the time required for rooting from the petiole—that is of rooting leaves without any stem tissue.



TEXT FIGURE 2. METHOD OF MAKING LEAF GRAFT

The piece of bark EFGH was fitted into the area ABCD and bound with grafting tape. A good fit of GH on AB was essential.

Such quick rooting clones as I.C.S. 47 and I.C.S. 60 were rooted as single node cuttings in a minimum period of 13–14 days. Similar leaves given optimal treatment took two months to root from the petioles. Plate 3 (b).

In this case the nutrients supplied by the leaves were presumably identical and the differences in time of rooting must be ascribed to differences in the conditions for the production of root primordia at the site where rooting occurs.

Two fundamental factors affecting the rooting response thus appear to have been established in the present work viz., (1) the nutrition of the shoots taken as cuttings and (2) the condition of the tissues at the site where the rooting response occurs.

In the case of the Imperial College clonal selections of *Theobroma cacao*—differences in the nutrition of the shoots under normal nursery conditions appear to be primarily responsible for differences in ability to root. Malnutrition of the shoots may, however, lead indirectly to an unfavourable condition at the site of rooting. Whatever the exact nature of the factors which bring about active cell division and differentiation of root primordia in the cambial region, these factors are most favourable in juvenile material. Malnutrition almost invariably results in a delay in the development of healthy green leaves. Shortage of nitrogen and/or excessive carbohydrate accumulation, and particularly shortage of iron results in delayed chlorophyll production. In such leaves protein hydrolysis and breakdown of the leaf tissues occurs when the shoots are separated from the mother tree and used as cuttings. There is, therefore, a distinct tendency to delay taking the cuttings until the leaves have attained a full green colour in order to avoid subsequent breakdown. In this case, however, the stem portion of the cutting may well be past the stage of development for optimum rooting, in other words the cambial tissues are no longer in the juvenile condition in which rapid differentiation of root primordia occurs.

Avoidance of conditions of malnutrition in the leaves enables cuttings to be taken from younger shoots since full colour is attained during the first stages of hardening of a recent flush and rooting of such material is very rapid.

As stated above—the condition of the cambial tissue at the site where the root primordia are differentiated would appear to be the primary cause of delayed rooting in the difficult rooting *Theobroma spp.* Although manipulation of the nutritional condition of the leaves enables many of these species to be rooted this effect is brought about by maintenance of the cuttings in good condition until rooting has occurred, rather than to an appreciable acceleration in the rate of rooting.

It follows that the main lines of investigation in such material should be aimed at bringing about changes in the activity of the tissues from which root primordia are differentiated. This problem does not arise in the case of any of the *Theobroma cacao* clones but would become important were it considered desirable to propagate other *Theobroma spp.* on a large scale and, of course, is of fundamental importance in the propagation of such tropical crops as Clove and Nutmeg, which are at present propagated almost exclusively from seed.

This problem has already been the subject of investigations on a large number of plant species with relatively little advancement in our knowledge of factors affecting rooting in difficult rooting species. Zimmerman and Hitchcock (1949) are of the opinion that changes in the structure of the protoplasm are primarily responsible for reduced rooting with age.

Many investigators have adopted the technique of producing juvenile forms of the plants under investigation by suitable pruning operations and to use such juvenile material for rooting.

(*d*) *Treatments applied at the base of the stem, designed to promote root induction*

Attempts were made to bring about changes in the cambial tissues at the base of the stem with a view to facilitating the production of root primordia.

In the first experiment on this subject semi-hardwood cuttings of somewhat slow rooting I.C.S. clones including I.C.S. 1, 21, 23, 27, 34 and 44 and normal cuttings of *Theobroma bicolor*, *Th. grandiflorum* and *Th. angustifolia* were used.

The treatments applied to the base of the cuttings were as follows :—

(i) Immersion for one hour in water at 5–6°C
(ii) Immersion for one hour at 35°C
(iii) Immersion for one hour at 40°C
(iv) Immersion for ½ hour at 50°C
(v) Treated with ether vapour for periods of 10 minutes, 20 minutes and 60 minutes.
(vi) Treated with ammonia gas for 10 minutes, 20 minutes and 60 minutes.

All cuttings were treated with the mixture of α Naphthalene acetic acid and β Indole butyric acid at the optimal concentration by the quick dip method immediately before planting.

The I.C.S. clones had rooted well after 22 days but there were considerable differences between the treatments. Of the water soaking treatments, immersion at 40°C for one hour had produced outstandingly good rooting—there being abundant roots 2–2½ inches in length. At the lower temperatures roots were fewer in number and were only approximately ½ inch to one inch in length. The immersion at 50°C had caused damage to a proportion of the cuttings but rooting had occurred above the damaged region.

The ammonia gas treatment had also caused damage in the I.C.S. clones but rooting had occurred above the damaged region.

Treatment with ether vapour improved rooting as compared to the controls but was not as effective as immersion in water at 40°C for one hour.

Rooting was not greatly accelerated in the other *Theobroma species* with the exception of *Theobroma bicolor* which produced roots after 5 weeks following treatment with ammonia gas for 10 and 20 minutes and with ether vapour for one hour.

However, marked swelling of the base of the stem occurred in *Th. grandiflorum* and *Th. angustifolia* following treatment with water at 40°C for one hour.

These experiments are only of a preliminary nature and are at present being repeated and extended. Preliminary results indicate that treatment of the base of the stem may aid rooting in certain difficult rooting species of *Theobroma*.

5. *The results of studies on nutritional factors in the rooting of cacao*

(*a*) *Methods of introducing nutrients into cacao cuttings*

Pyke (1931–33) had considered the possibility of modifying the nutritional status of the shoots selected as cuttings but dismissed the possibility on account of mucilage exudation which interfered with uptake of extraneously applied solutions and confined his nutritional manipulations to ringing experiments.

It has been shown in section 2 (*a*) that ringing had far more effect than merely increasing the carbohydrate status and resulted in complicated changes in the shoot as shown by mineral starvation, failure to flush, &c.

It was, therefore, necessary to devise alternative methods of nutritional manipulation.

The first method tried was to stand the cuttings in the solutions to be tested allowing a certain amount of transpiration to occur. This work was commenced in the dry season of the year 1949 ; severe wilting of the leaves occurred. There was some evidence of blockage of the xylem elements at the base of the shoot. Shoots were, therefore, placed in 0.02 per cent. sulphur dioxide solution—a technique which is used in sugarcane to prevent blockage of xylem elements by polyphenol oxidase activity. This procedure prevented wilting in some of the shoots but not in others: those in which wilting was prevented remained turgid for 6–7 days and finally became yellow as a result of the toxic action of the sulphur dioxide solution.

In those in which wilting had occurred it was shown that water deficit had resulted in the presence of air or vapour bubbles in the xylem elements resulting in disruption of the upward flow of water.

The procedure of introducing solutions by standing cuttings in the solution was abandoned in favour of introduction through the leaves. Normal stem cuttings with a half of each leaf removed were inverted in large museum jars with the basal end of the stem just emerging above the level of the solution. Experiments with acid fuchsin showed that appreciable quantities of solution could be introduced into the cutting by this means.

Two other methods were also successfully used. The first method consisted of excising at the base of the lamina all the leaves except one on the shoot to be injected, about one week before the date of making the injection. This allowed an abscission layer to be formed at the base of the petiole thus effectively sealing the wound. To introduce solutions into the shoot the remaining leaf was cut transversely half-way along the lamina and the basal

portion immersed in a waxed paper bag containing the solution to be introduced. Uptake was allowed to take place for two days. For testing the effect of nutrients on leafless cuttings, the remaining half leaf through which the injection was made, was removed prior to planting the stem cutting.

The third method, which was particularly useful for injecting leafy cuttings with extraneous nutrients consisted of forcing the liquid into the cutting through the base of the stem under pressure. Preliminary experiments with dyestuffs showed that the whole tracheal system was impregnated within a few minutes—including the finest veins in the leaf. The introduced dyestuffs accumulated in larger quantity in the vicinity of any wounds, such as those caused by insect or wind damage, in the lamina and the solution oozed out of even the finest veins if the latter were cut.

The apparatus used consisted of a U-tube filled with liquid and connected to a knapsack sprayer—the pressure used was 30–45 lb. per square inch.

(*b*) *The effect of introduction of nutrients on the rooting of leafless cuttings*

Using methods 1 and 2 a large number of experiments were carried out on the rooting of leafless cuttings supplied with extra nutrients.

In the first experiments the main nutrients supplied consisted of sucrose and sucrose in combination with inorganic salts such as potassium nitrate, urea, calcium nitrate and sodium phosphate. Cuttings were treated at the base with the optimum hormone treatment, roughly 80 per cent. of the leafless cuttings which were given added sucrose had rooted within one month. The cuttings given sucrose and urea had also rooted but the rooting was slightly poorer than those given sucrose only. The other mineral salts used had toxic effects which resulted in the rotting of the cuttings.

Several experiments of a similar type proved conclusively that sucrose was by far the most important factor involved and rooting was as good in leafless cuttings supplied with sucrose as in ordinary leafy cuttings. In a few experiments urea had a slightly beneficial effect but generally it had no effect. Sucrose was used at a concentration of 3 per cent. and 4 per cent., urea at 1 per cent. After the roots had been formed the leafless cuttings were transplanted into baskets in the usual way and in due course the buds sprouted. The leaves formed were, however, thin and translucent and lacking in body and finally fell off. The rooted leafless cuttings invariably died. It was apparent that the reserves of sucrose which could be introduced into the stem, although adequate for the production of a normal root system, was inadequate to supply the developing leaves.

In further experiments attempts were made to introduce larger quantities of nutrients into leafless cuttings by immersing the cuttings in the solution to be introduced and evacuating under a suction pump. By this method all the intercellular spaces were filled with solution, asphyxiation of the cuttings resulted and death occurred. Recently this type of experiment was repeated with the modification, suggested by Dr. E. J. Maskell, that after infiltration the cuttings were allowed to dry out until they had attained approximately their original weight before planting. In the one experiment carried out with this modification the cuttings rotted within two weeks of placing them in the propagating bins.

It has, therefore, not been possible to introduce sufficient reserve materials into a leafless cutting to enable it, not only to be rooted, but also to be established as an independent plant.

If shoots on the tree treated by injection with sucrose through one half leaf (method 2) were planted without removal of the half leaf, not only were roots formed but the plant could be established. The half leaf could apparently supply the extra amount of nutrients required for the growth and development of the new shoot ; although similar control cuttings not given sucrose failed even to root.

(c) *The effect of the introduction of nutrients on the rooting of leafy cuttings*

The influence of a large number of possible nutrients on the rooting of leafy cuttings of clones which are generally slow rooting was investigated. The first method of injection, i.e., through the leaves, was principally used. It was found, however, that in the wet season when there is no water deficit in the shoots, appreciable quantities can be introduced by standing the shoots with their base in the solutions for 24 hours. When using this method the nutrients to be supplied were applied in the same solution as the hormone application by the dilute solution method.

Larger quantities of nutrients can be introduced under pressure (method 3) and this method was largely used in later work.

The criterion used in the selection of the substances to be tried was their activity in the growth of roots in aseptic culture. Substances tested included sucrose, amino acids, particularly arginine, White's nutrient solution, coconut water, tomato juice, the whole range of B vitamins, sodium glycerophosphate, Vitamin C, yeast extracts, manganese sulphate, &c.

It is not proposed to discuss in detail the numerous experiments which were carried out, many of which produced negative results.

It was found that most of the substances finally selected, with the exception of sucrose, were ineffective alone but improved rooting when combined with others. The presence of sucrose was necessary. Without sucrose no beneficial effects were produced by various amino acids, vitamins, and manganese sulphate. Mixtures of these in combination with sucrose, however, produced stronger and more abundant roots and in particular maintained the leaves in healthy condition for longer periods than sucrose alone.

The influence of an additional supply of nutrients was particularly marked in the case of so-called difficult rooting clones. It must be emphasized that no distinction had previously been made between slow rooting of material which otherwise remained in prime condition and cuttings which are difficult to establish because of yellowing, deterioration and shedding of leaves in the propagators. It was found that the latter phenomenon was responsible for low rooting percentage in many of the clones tested.

Experiments were carried out with slow rooting clones such as ICS 56, ICS 55, ICS 23 and ICS 1 to which nutritional treatments were applied.

The results of such an experiment with ICS 1 are given in Table XII.

TABLE XII—*Effect of Nutritional Treatments on the Rooting of ICS. 1 (20 cuttings in each treatment)*

Treatments	No. of cuttings rooted after 24 days	No. of roots	Total length of roots (ins.)
1. Controls (untreated)	13	32	26
2. β IB + α NA only	16	114	171
3. β IB + α NA + 3% sucrose ...	17	136	230
4. β IB + α NA + 3% sucrose ... + 200 ppm. arginine	19	149	256
5. β IB + α NA + 3% sucrose + 200 ppm arginine + 200 ppm. $MnSO_4$ + 1 ppm. Vitamin B1.	18	136	222
6. β IB + α NA + 3% sucrose ... + 0.1% ammonium sulphate + 200 ppm. $MnSO_4$ + 1 ppm. Vitamin B1.	20	147	188

It is apparent that optimum hormone treatment is in itself an important factor and that the activity is enhanced by sucrose and possibly arginine.

Similar results were obtained in an experiment with ICS 56 and with ICS 55. The rooting responses of these clones are shown in Plate 1.

The optimum treatment produced an abundance of roots on these normally slow rooting clones in 24 days.

Similar experiments with other clones demonstrated that when given optimum hormone treatment and additional nutrients all the so-called difficult rooting ICS clones became very easy rooting.

The practical interpretation of this finding and the adjustment of the nutritional status of the shoots to be used as cuttings by manipulation of the environment in the nursery and the conditions during rooting are discussed in a later section of this report.

That the nutritional condition of the cutting was of great importance though not the primary factor involved was shown by feeding experiments carried out on the difficult rooting *Theobroma grandiflorum* and *Th. angustifolia*. Only a single tree of these two species exist at the Imperial College of Tropical Agriculture and previous attempts to propagate from these trees had been unsuccessful. Cuttings of the two species given optimum hormone treatment and with conditions otherwise satisfactory failed to root within 6 to 8 weeks. Thereafter, there was veinal yellowing and necrosis of the

leaves and although one or two roots were produced the cuttings were almost moribund by this time. A supplementary nutrient solution containing sucrose, amino acids and Vitamin B1 were introduced into cuttings under pressure. Cuttings thus reinforced with nutrients remained in healthy condition without any sign of leaf yellowing for over three months. By this time about 20 per cent. of the cuttings had rooted, though the characteristic root development was one to three large, thick, roots and not the whorl of roots produced in *Theobroma cacao* stem cuttings. *Th. angustifolia* rooted somewhat earlier than *Th. grandiflorum* but root growth after potting out was better in the latter species.

The interesting fact is that even with optimum nutritional conditions and optimum conditions in the propagation chambers these varieties required a minimum of two months or more and generally three months before rooting occurred and even then the percentage rooting was low. Some cuttings rooted after five months in the propagators. It was only by reinforcing the natural nutrient reserves that cuttings could be maintained in healthy condition for this length of time.

It was seen from the results of grafting experiments in which leaves of easy rooting *Theobroma cacao* were grafted on *Th. angustifolia* and *Th. grandiflorum* that rooting of the latter only occurred after several months. These species are, therefore, intrinsically slow rooting plants and the evidence suggests that the cause of this lies in the nature of the stem tissues from which the root primordia are differentiated rather than to any deficiency in supplies of either formative or nutritive material from the leaves.

The symptoms, though not the cause, of the condition at the base of *Theobroma spp.* which are difficult to root are seen in reduced cambial activity as compared to *Theobroma cacao*. This applies both to the cambium and to the phellogen. The slowing down of cambial activity is often associated with production of abundant flowers on quite young stem tissue. Even in *Theobroma cacao* it has been noted that where flowers are produced on shoots to be taken as cuttings, the rooting of such cuttings is generally unsatisfactory. There would appear to be, therefore, a condition of the cambial tissue involved. Treatment with root inducing substances may cause very active development of tissue from the cambium as in *Th. cacao* or it may have very little effect as in *Th. bicolor* and to a lesser extent in *Th. grandiflorum* and *Th. angustifolia*.

6. *The growth of cacao stems in aseptic culture*

As an additional approach to the problem of the nutritional factors involved in the rooting of cacao attempts were made to grow pieces of stem tissue in aseptic culture. Liquid cultures conforming to P. R. White's formula (White 1937) were used and pieces of green cacao stems about 5-6 cm. long were cultured. Considerable difficulties were experienced in obtaining sterile stem material. Surface sterilization was inadequate as after a week for two fungal spores which had penetrated into the lenticels of the stems requently produced fungal colonies.

Sterile pieces of stem were finally obtained by judicious infiltration in a 0.1 per cent. solution of the organo mercurial disinfectant, aretan, under vacuo followed by washing with sterile water. These leafless stem segments remained in good condition for over three months and a considerable quantity of new tissue was added. This new tissue developed from the phellogen and consisted of long cells bearing a close resemblance to the palisade tissue of a leaf. Chloroplasts were present and as a result of the development of this tissue the chlorophyllous layer normally occurring immediately below the hypodermis became deeply seated in the stem. No roots were produced in these cultures. From what is now known of the oxygen requirements for root initiation, it is probable that no roots would be produced under conditions of immersion and it would be necessary to repeat this work in suitably aerated cultures.

7. *The effect of external conditions during rooting*

(*a*) In his original investigations Pyke (1931–1933) had made an investigation of the gross external conditions and described the conditions under which rooting occurred. The time which elapsed between planting and potting out in the earlier investigations at the Imperial College was rather long according to modern standards—roots were 2 to 3 inches long after 4 to 5 weeks and potting out was effected at eight weeks after striking. The shade used over the propagators—one layer of domestic calico cloth—was also expensive to maintain and had in recent years been replaced by slatted bamboo.

The rooting results with the conditions existing were not very satisfactory and the responses to sucrose obtained in the nutritional experiments indicated that the photosynthetic activity of the leaves was inadequate.

(*b*) *Light and Temperature*

Since it is difficult under the conditions in the propagation chambers to separate the effects of light and of temperature these two factors are considered together. Numerous experiments have been carried out on the influence of light and of temperature. Controlled experiments using artificial light and water cooling screens were made. At a light intensity of 120 foot candles for 10 hours per day and a temperature of 32°–33°C single leaf cuttings lost carbohydrate at a faster rate than it was manufactured and starvation symptoms appeared within a week. With an intensity of 75 foot candles for 24 hours and a temperature of 27°–28°C the leaves remained healthy and rooting occurred in four weeks, in the case of quick rooting clones. It was noted, however, that certain clones although remaining green and healthy did not produce roots under such low light intensities. As the light intensity in the propagating bins was frequently below 100 foot candles and, in dull weather, much lower, it was decided that the permanent overhead shade previously in use might be sub-optimal. Accordingly a mobile wooden screen was constructed over one set of 12 propagating bins on the Venetian blind principle. It was possible with this screen to provide a more constant light intensity by varying the angle of the slats. Additional light was provided in the early morning and late afternoon by turning the slats in the direction calculated to let most light through. When horizontal, the slats let through about 15 per cent. light and when vertical about 90 per cent. light. This

procedure resulted in a spectacular improvement in the appearance of the cuttings and in the ease of rooting. At a light intensity varying during the day from 250 to 700 foot candles slow rooting clones rooted almost as readily as quick rooting clones. In these experiments the temperature and humidity of the propagating bins were controlled. The atmosphere inside the bin was kept at practically 100 per cent. humidity and the temperature was not allowed to rise above 30°C. Thermohygrographs were used to record these factors and the temperature was reduced when there was a tendency to rise over 30°C by reducing the aperture between the slats and on a few particularly hot days by extra watering during the midday hours.

When, as a result of allowing extra light to pass into the bins the temperature rose to 32°C for lengthy periods, the extent of rooting was considerably reduced. Under these conditions the humidity may also drop and although not noticeable immediately, yellow patches may develop on the leaves after a few days as a result of excessive moisture loss during the period when the temperature rose.

One good advantage of the adjustable screen was the possibility it afforded of letting through 90 per cent. of the available light in dull weather, when the total light intensity may be as low as 400 foot candles.

It should, of course, be possible to have such a screen made of metal laths with the apertures thermostatically controlled by a thermostat placed inside the bins but such equipment would be expensive, and would not be justified.

The information obtained from the optimum light and temperature experiments was utilized in the preparation of a permanent shade of split bamboo over the whole propagating bins. This shade was constructed so as to allow 30 per cent. of full sunlight to pass through.

The covers of the bins reduced this to just under a half, i.e., approximately 12 to 14 per cent. of available light entered the bin.

The overhead shade was a compromise calculated to give an average light intensity of approximately 250 to 350 foot candles inside the propagating bin : maximum light intensity within the bins on bright cloudless days was 650 to 700 foot candles.

Several experiments on rooting responses were carried out with this overhead shade and with varying transmittance of the covers of the bin.

Vinalite plastic cloth was used in place of glass on the frames of the bin covers and transmittance varied by placing one and two layers of cheesecloth and one and two layers of calico cloth. The best results were obtained with one layer of calico.

In order to determine whether light intensity under this procedure was adequate certain propagators were given extra light during dull days and by extending the length of day by overnight illumination. Electric lamps were used producing 100 foot candles inside the bin. Temperature was kept down by insertion of a water screen. There was no benefit whatsoever from the provision of extra light.

Light measurements in the present work were carried out with a Weston illumination meter fitted with a quartz screen which made the instrument sensitive to approximately the wave-lengths to which the human eye is sensitive. The instrument measured intensities up to a maximum of 5,000 foot candles. Full sunlight in Trinidad on a bright day was considerably higher than the maximum range of the instrument. Some investigators have used photographic exposure meters for the measurement of the optimum light intensity for the propagation of cacao and have failed to calibrate these instruments—which are, in fact, generally designed to measure reflected light. This has resulted in gross undervalues (Cobley 1942, Burchardt and Jörgensen 1950) for the optimum light intensity for cacao nurseries and for cacao propagation (values given by these authors approximate to 15–18 foot candles).

The influence of light intensity alone separated from the complicating effects of temperature was further investigated in cuttings rooting in open beds under a fine mist spray. In this case the temperature of the cuttings was fairly constant owing to the constant cooling effect of the spray and was below 30 °C on the hottest day. Comparison was made of rooting in full sunlight and in various fractions of full sunlight.

With full sunlight there was severe bleaching of chlorophyll under a continuous spray and the bleached tissues were liable to internal breakdown and fungal attack. Reduction of full sunlight to 75 per cent. light prevented the excessive bleaching but slow decomposition of chlorophyll resulting in a yellowish green appearance of the leaves was apparent after two weeks or so. The light intensity under this system has been continually reduced with resulting better appearance of the cuttings and no reduction in rooting. The optimum light intensity with this method of propagation was approximately 20 per cent. of sunlight reaching the plants. This was achieved with an overhead shade letting through 25 per cent. sunlight the spray particles further reducing the light intensity to approximately 20 per cent. of full sunlight.

In so far as rooting is concerned there was little or no difference between 20 per cent. of sunlight and 33 per cent. of sunlight in the open spray beds but the leaves under the former light intensity maintained a healthy dark green colour throughout the rooting process, whereas there was a tendency to pale somewhat, particularly in some clones, with the latter light intensity.

The paling of the leaves was due to accumulation of carbohydrates in amounts which utilised all available nitrate in the leaves, the effect being analagous to that which occurs in cacao leaves in the field under high light intensity and which also occurs in the leaves of ringed shoots on the growing tree.

The experiments have shown conclusively that light intensity divorced from the complicating effects of temperature and humidity is not a crucial factor in the rooting of cacao providing that the intensity and duration is within certain limits. This is shown by the facts—

(*a*) That cuttings have produced roots in complete darkness after introducing adequate supplies of sucrose and amino acids before striking the cuttings.

(*b*) That 24 hours exposure to light did not produce any better rooting than the normal day length.

(*c*) That satisfactory rooting occurs in the open spray bed at light intensities from 15 per cent. to 80 per cent. of sunlight. The object of using a light intensity of 20 per cent. to 25 per cent. sunlight in the open bed is in order to maintain the leaves of the cutting in the best condition.

This light intensity applied to cuttings planted in such a way that each cutting was exposed to the full incident light stated. If, on the contrary, the cuttings were planted more densely so that considerable mutual shading took place then obviously a higher light intensity could be used. Thus Bowman (1948) found that full or nearly full sunshine was optimal with cuttings crowded in beds at the rate of about 80 cuttings per square yard.

(*c*) *Rooting media and the air—water relationship in the rooting media*

Pyke (1931–33) investigated a limited number of rooting media and selected a particular grade of sand having the properties of somewhat coarse but relatively uniform grain size and relatively free draining as the most suitable rooting medium. It is known as Toco sand after the locality from which it is obtained and has been in general use in Trinidad as a rooting medium for cacao cuttings for some years.

It was noticed after some time that there was a variation in the rooting of cuttings in different parts of individual chambers, those towards the back rooting better than those towards the front. Of the three possible causes of this—somewhat less light, slightly lower temperature and interception of more water in the periodic watering ; the latter was found to be the causative factor. This result implied that the mean water content of the Toco sand was suboptimal for best rooting. To test this theory, the sand instead of being loose in the bin, was placed in earthenware pots with an open drainage hole at the bottom. This would have the effect, by slightly delayed drainage, of increasing the mean water content of the sand. 50 stem cuttings of ICS 1 were planted in Toco sand in six inch pots and compared with Toco sand free in the bin. The amount of rooting after 24 days is shown in Table XIII.

TABLE XIII. *Rooting after 24 days*

Medium	No. of cuttings rooted	No. of roots	Total length of roots (inches)
Toco sand in pots ...	45	137	127
Toco sand free in bins ...	20	61	45

The watering regime was the usual one of three per day. The cuttings in both treatments finally rooted but rooting was greatly accelerated in the cuttings in the pots as compared to those in sand free in the bins.

Using three watering schedules, several locally available rooting media were tested including—Toco sand, river sand, fresh sawdust, crushed charcoal, imported silica sand (relatively fine grain), potting mixture (consisting of one part vegetable compost and one part river sand) and coconut fibre. The watering schedules were :—

1. Watered once every two hours.
2. Watered three times per day (this was the current practice).
3. Watered once at the beginning of the experiment but no further watering—cuttings placed in boxes over a free water surface to maintain a fully humid atmosphere.

No root measurements were made, rooting being estimated by observation. With the first watering schedule Toco sand was markedly superior to all the other media. There was practically no rooting in the potting mixture and rotting of the base of the cutting was common. In the charcoal, river sand and imported silica sand white callus rods of undifferentiated tissue emerged through the lenticels and rooting was poor. There was considerable rotting of the base in the fresh sawdust.

With the second watering schedule the charcoal, silica sand and river sand were superior to the Toco sand, the potting mixture behaved as in the first watering schedule. Coconut fibre was about equally effective to the Toco sand.

In the third watering schedule the results as a whole were poorer but the best media were silica sand and river sand.

These preliminary experiments demonstrated that an evaluation of the merits of a particular rooting medium would be useless unless the watering schedule was also taken into consideration.

Experiments were, therefore, carried out to evaluate the merits of the different rooting media *at whichever watering schedule was optimal for each particular medium.*

Of the rooting media tested in the preliminary experiments the following were abandoned on the grounds of inadequate supplies for universal use, high cost, or unsuitability—silica sand, crushed charcoal, potting compost.

Further experiments were carried out with Toco sand, locally available river sand, and partly rotted sawdust.

River sand was fractionated into a coarse gravely fraction, a medium grain sand and a finer sand. This fractionation showed, however, that the river sand locally available was most heterogenous in particle size and each fraction contained an appreciable amount of finer particles.

After some time in the bins the river sand tended to pack and rooting results, even at optimum watering, were somewhat inferior to Toco sand.

In the course of preparation of improved potting mixtures large quantities of composted sawdust had been prepared. Ordinary sawdust of mixed timber species—mostly hardwood—available locally in large quantities was composted with farmyard manure for nine months. This produced a very dark-brown material of crumbly structure free from any toxic materials present in fresh sawdust and with very different physical characteristics. Preliminary experiments with sawdust compost having shown considerable promise, extensive experiments were carried out on comparisons of this material with Toco sand. It was established that rooting in Toco sand improved consistently with more frequent watering from three waterings per day to watering every two hours. There was no further improvement in the rooting with more frequent watering but provided that drainage was adequate there was no deterioration in rooting with more frequent watering. The percentage rooting after three weeks using ICS 1 was 62 per cent. with two hourly watering and 61 per cent. with hourly watering.

With the sawdust compost rooting medium the situation was quite different. In a comparison of watering every two hours compared with watering every hour 84 per cent. had rooted in three weeks in the two hour watering compared with 80 per cent. in the hourly watering. Further, 72 per cent. of those which had rooted had sufficient roots for transplanting in the two hour watering compared to 52 per cent. in the hourly watering.

A further experiment was carried out with the sawdust compost in which watering every three hours was compared with watering every two hours. The two clones ICS 1 and ICS 95 were used. The percentage of cuttings which had rooted sufficiently well to be potted out after 25 days was as shown in Table XIV.

TABLE XIV

	ICS 1	ICS 95
Watered every two hours ...	76%	86%
Watered every three hours ...	88%	93%

(*d*) *Amount of water at each watering*

There was a further factor which was of importance in the water relations of the rooting medium, viz. : the quantity of water applied at each watering. With Toco sand, providing that the rooting bed had been well laid to ensure perfectly free drainage, there was no upper limit within reason to the quantity of water which could be applied. On the other hand insufficient water at each watering had a similar effect to less frequent watering. In the sawdust compost, on the contrary, large amounts of water at each watering were deleterious—resulting after a time in too rapid rotting of the compost with resulting loss of structure and a tendency to stickiness and clogging of the medium.

Normally, watering was carried out with a rose attached to a hoespipe : in larger propagating stations jets are installed in the bins and operated from a control valve. In the present experiments it was found that the most suitable watering technique for the sawdust compost was to water

once every three hours using a sprayer with a reasonably fine nozzle or a watering can fitted with a fine rose. The object of this type of watering is to keep the cuttings cool and the atmosphere inside the bin humid rather than to increase unduly the free water content of the rooting medium. With the optimum watering schedule for each medium the sawdust compost was proved to be superior to Toco sand as a rooting medium. The only disadvantage of sawdust compost is that it is not a permanent rooting medium. Whereas decomposition in large heaps in the open was a slow process, decomposition in the propagating chambers was more rapid as a result of the frequent watering. The heavier the watering the faster did the material lose its physical characteristics. With the light watering which was optimal for the best rooting responses the material kept in suitable condition for about six months. Its advantages are great—

(*a*) it is an excellent rooting medium.

(*b*) it is capable of being produced in most countries thus eliminating inferior rooting results caused by lack of suitable sands locally available and so making possible the utilization of a satisfactory technique in all countries.

(*c*) as is mentioned in a later section it offers the possibility of dispensing with " hardening-off " chambers.

(*d*) when its utility as a rooting medium has deteriorated it remains a most useful component of potting mixtures.

(*e*) *Other rooting media*

Extensive experiments were carried out with two other types of rooting media, viz. : vermiculite and slate wool.

Vermiculite is a heat expanded micaceous mineral and slate wool(1) is a material somewhat similar to glass wool manufactured by heat expansion of slate. Four grades of Vermiculite were tested—a horticultural grade marketed under the name of " Exflor "(2) and grades (3) known as " fines ", " medium " and " coarse " not especially specified for horticultural work.

The watering schedule for the Vermiculite was similar to that of composted sawdust, i.e., light spray watering every three hours during the day. Under these conditions vermiculite was shown to be an excellent rooting medium slightly superior to sawdust compost. With usage, however, it has a tendency to pack and is then inferior to fresh sawdust compost. Under light spray watering there was little to choose between the various grades, but under heavier watering the coarser grades gave better results. Slate wool gave satisfactory results under heavy watering but was inferior to vermiculite in covered propagators.

(*f*) *A summing up of the effects of external factors in the rooting of cacao cuttings*

When the effects of the more important external factors are considered it is apparent that the importance of temperature is limited to ensuring that the temperature is not allowed to rise above 30°C—optimum rooting taking place within the temperature range 27°–30°C. The effect of light intensity is important in that it must be high enough for a satisfactory photosynthetic rate to be maintained. Providing that complications of high temperature

1. Supplied by the manager, Dinorwic Quarries, Port Dinorwic, N. Wales.
2. Supplied by Mullard Horticultural Engineering Co. Egham, Surrey.
3. Supplied by Mr. Potter of Geddes Grant & Co. Ltd., Port-of-Spain, Trinidad.

and low humidity are not allowed to interfere and providing that the leaves of the cuttings are not mutually shaded by overcrowding optimum rooting takes place between 15 per cent. and 20 per cent. of full sunlight. At higher light intensities a degree of decomposition of chlorophyll associated with a deterioration in the condition of the cutting results. Within the propagating bins the optimum light intensity varies from 200 foot candles in cloudy weather to 700 foot candles during bright periods.

A slight drop in the humidity can cause localized drying out of areas of the lamina of the leaves—again resulting in a deterioration in the condition of the cutting. Probably the most important of all the external variables is the air-moisture relations at the base of the cutting. Certain visible symptoms are associated with unsuitable conditions at the base of the cutting. Badly drained rooting beds or media in which there is a suboptimal supply of oxygen results in rotting of the basal end. When the degree of aeration and drainage is inadequate but nevertheless not so severe as to cause rotting of the base, callus rods are formed from the phellogen or cork cambium and protrude through the lenticels. When the degree of aeration is excessive and the moisture content of the medium too low a thick callus pad is produced at the extreme base of the cutting but no callus rods emerge through the lenticels. When the air-moisture relations of the rooting medium is optimal there is neither a marked formation of lateral callus rods nor a heavy callus pad at the base. Although roots may eventually be formed under conditions of defective or excessive moisture in relation to the air supply the differentiation and development of root initials is considerably delayed. The optimal condition as regards the air-moisture relations at the base of the cutting for rapid root development is confined to relatively narrow limits. For the grade of Toco sand used in this work, for example, the optimum is not at the free moisture holding capacity of the sand but at a water content somewhat higher than its free water holding capacity.

With all factors within the optimum range almost 100 per cent. of the cuttings of easy rooting clones such as ICS 60, ICS 47, ICS 95 root sufficiently well to be potted out in 17–18 days and the slower rooting clones such as ICS 1 in 21–23 days.

When the conditions are sub-optimal, however, delay in rooting in the case of the shy rooting clones is far longer than in the case of the easy rooting clones : in other words the range of optimal conditions is considerably narrower in the latter clones.

8. *Studies in the Technique of Rooting Single Leaf Cuttings of Cacao*

(*a*) *Problems encountered in the rooting of leaf cuttings*

G. Stahel (1948) has been the pioneer in the commercial propagation of cacao from single leaf cuttings and has within recent years produced several hundred thousand cacao plants for field planting by this method. Others, have found the method difficult of application on a commercial scale. At an early stage in the investigation described here, the writer directed his researches to the propagation of cacao leaf cuttings. As a result of this work numerous difficulties which were experienced have been overcome and a brief description of some of these difficulties and the causative factors involved may be of value to those intending to adopt this technique of producing rooted cacao plants.

In order to test the possibilities of the method 1,000 single leaf cuttings consisting of 10 cuttings of each of the 100 ICS clones were planted. The cuttings were in prime condition and were treated witb indole butyric acid at 2 mgrm/millilitre as recommended by Stahel. They remained in perfect condition for about one week : subsequently a veinal yellowing spreading rapidly from the base of the leaf became apparent. The condition was much worse in some clones than in others : within two weeks the number of cuttings affected varied from none in some clones to the whole ten in others. The writer had not at the time seen Stahel's original Dutch paper but only an English abstract and so was not familiar with tne fact that Stahel had also experienced this yellowing of the lamina associated primarily with the veinal system.

Sectioning of the vascular tissue of affected leaves indicated that the vascular tissue serving the affected parts of the leaf were discoloured along their whole length into the stem portion of the cutting. It appeared, therefore, as if some pathogenic organism was being carried up in the vascular tissue from the cut surface of the stem portion, or alternatively, that toxic substances produced either by bacterial or fungal activity, or by purely biochemical action at the cut end of the stem was responsible for the leaf yellowing.

Numerous experiments were carried out using disinfectants for treating the cut ends in association with steam sterilization of the rooting medium. Professor Baker also kindly undertook to make cultures of the discoloured vascular tissue from affected leaves. These cultures showed an unidentified bacterium consistently associated with the discoloured vascular tissue. The bacterium was isolated in pure culture and inoculations of fresh single leaf cuttings made with the inoculum. The characteristic yellowing did not result, however, on fresh material and only developed when cuttings had been in the propagating chambers for some days. The usual disinfectants either were ineffective or were themselves toxic. Organo-mercurial disinfectants such as aretan, agrosan, &c. were tested, diluted in talc and incorporating hormone treatment in the same talc, but were generally toxic.

Several experiments were carried out with enzyme inhibitors including potassium ethyl xanthate, sodium azide, salicyl aldoxime, sodium diethyldithio-carbamate and iodoacetic acid. Of these, sodium diethyldithiocarbamate and iodoacetic acid were the most effective. Treatment of the stem portion of the cutting by dipping in M/1000 solutions of these inhibitors delayed the onset of the yellowing symptoms very appreciably.

It was found, however, that experimental results were frequently inconsistent and that an environmental variable was involved. A succession of bright sunny days resulted in few or no symptoms whereas dull weather resulted in some symptoms even in those cuttings treated with the enzyme inhibitors.

Moreover, injection of the cuttings with sucrose solution greatly delayed or even prevented appearance of the symptoms. An experiment was carried out in which single leaf cuttings were injected with sucrose alone and with sucrose plus arginine. These together with untreated controls were placed in propagation chambers in complete darkness. After five days all the

untreated cuttings were showing acute yellowing, but the injected cuttings were still green. By 15 to 18 days the injected cuttings were also becoming yellow but some of the ones treated with sucrose and arginine were still green and had produced roots.

It was concluded from these experiments that the cuttings were, in fact, starving and that the bacterium which caused necrosis of the vascular system was only a weak parasite merely attacking the leaves when nutrient reserves had fallen to very low levels. It was the results with single leaf cuttings that led to the light experiments described in section 7 (*b*) of this report. When the previously existing permanent shade was replaced by a new shade letting through 30 per cent. light, the starvation symptoms in the leaf cuttings disappeared.

Changes in the dry matter of leaf cuttings whilst rooting were followed by means of leaf-punch samples. Even under satisfactory light conditions there is a net loss of dry matter from the lamina during the first week but the loss is small (less than 5 per cent.) In three weeks the lamina had practically regained its original dry weight as shown in Table XV.

TABLE XV. *Change in dry matter per cent. of original dry matter*

	After first week	After three weeks
ICS 47	—4.05	—2.1
ICS 1	—2.70	+0.9
ICS 6	—3.80	+0.1

Nutritional experiments with single leaf cuttings showed that sucrose greatly increased rooting when the light intensity was suboptimal but when the cuttings were exposed to adequate light there was no further advantage from the use of sucrose. Treatment with Vitamin B1 was also inutile as shown in Table XVI.

TABLE XVI. *Results of Vitamin B1 Treatment of Leaf Cuttings*

Treatment	Cuttings planted	No. of cuttings rooted	No. of roots	Total length of roots (inches)
α NA + β IB alone	14	14	48	50
α NA + β IB + 1 ppm Vit. B1	14	9	28	20
α NA + β IB : watered with 1 ppm Vit. B1 after 3 days...	14	12	37	34
α NA + β IB : watered with 1 ppm Vit. B1 after 7 days...	14	11	30	22
α NA + β IB : watered with 1 ppm Vit. B1 after 12 days	12	9	32	32
α NA + β IB watered with 1 ppm Vit. B1 after 3, 6, 9, 12 and 15 days	12	10	54	51

A large number of further nutritional experiments were carried out with single leaf cuttings but providing that the cuttings were in prime condition when taken from the nursery and the light intensity and air-moisture relations in the propagating chambers were adequate no significant responses to additional nutrients were obtained. Indeed, almost 100 per cent. rootings was obtained in the untreated cuttings in 23 to 24 days. If, however, the leaves in the nursery were pale and showed slight nitrogen deficiency and, in particular, if the light over the propagating bins was suboptimal a response to injection of sucrose and amino acids was obtained. Nutrients were introduced in these experiments in two ways (*a*) by inverting the cut blade of the single leaf cutting for two to three hours in the solutions to be introduced and (*b*) by injection of the whole shoot under pressure before dividing into single leaf cuttings.

Additional experiments were carried out in which the leaf cuttings were sprayed with nutrients whilst in the propagators. Sulphamezathine and/or shirlan was used to prevent fungal attack of the treated leaves.

Substances used for spraying included sucrose, sucrose + 0.1 % ammonium sulphate, sucrose + arginine + asparagine + glycine (the amino acids at 200 ppm each) and sucrose + amino acids + manganese sulphate + B vitamins.

As recorded above, providing that conditions were otherwise optimum no significant improvements in rooting occurred.

(*b*) *The effect of nursery shade and of mineral deficiencies on the rooting of cacao cuttings*

(*i*) *Effect of light intensity in the nursery on the rooting of cuttings*

In order to test more accurately the effect of light intensity in the nursery on rooting, cacao plants of the clones I.C.S. 1, I.C.S. 60 and I.C.S. 95 were grown under light intensities of 15 per cent., 25 per cent., 50 per cent., 75 per cent. and 100 per cent. of full daylight. Twelve cuttings from each clone in each light intensity were taken when the plants were 15 months old. The 180 cuttings in the experiment were individually tagged and were struck at random in the propagators.

The cuttings were lifted and examined after 21 days. Only two cuttings out of the 180 planted had failed to root but there were considerable differences in the length of roots and in the general appearance of the cuttings.

The leaves kept in the best condition in the plants grown in the light intensities of 15 per cent., 25 per cent. and 50 per cent. of full sunlight. Some yellowing and breakdown of leaves had occurred in the plants grown in 75 per cent. sunlight and this condition was greatly accentuated in the plants grown in full sunlight. The heaviest rooting (abundant roots 3 to 4 inches in length in three weeks) had occurred in the 25 per cent. and 50 per cent. light treatments. The roots were generally shorter, although almost as numerous, in the cuttings grown under 15 per cent. light and there was not a great deal of difference between rooting under this treatment as compared to plants grown in 75 per cent. light. Rooting was significantly lighter in the cuttings from plants grown in full sunlight.

With increasing size of the plants and resultant mutual shading—it is probable that the optimum light intensity would approximate 50 per cent. of full sunlight since at this stage (plants 15 months old) the best results were obtained within the range 25 to 50 per cent.. 15 per cent. light being decidedly inferior. The comparative rooting of the cuttings of I.C.S. 95 (which is typical of the results obtained with the other two clones) are shown in Plate 12.

(ii) *Mineral deficiencies and their effect on the rooting of cuttings*

In Trinidad and indeed in most of the West Indian islands which the writer has visited, cacao frequently shows symptoms of mineral deficiency. In nurseries which are given periodic dressings of nitrogen, potash and phosphate, seasonal deficiency of nitrogen may still occur. It is particularly evident after long periods of wet weather when the rate of soil nitrification is low and may also be induced by heavy mulches of organic material without additional nitrogen fertilizer. A considerable improvement of nursery trees occurred as a result of small but frequent applications of artificial fertilizers (approximately ¼ lb. of sulphate of ammonia and muriate or sulphate of potash and two ounces superphosphate to each tree every two months). In addition to nitrogen, the most frequent deficiency met with in the Caribbean area is that of iron. Rarely, deficiencies of manganese, copper and magnesium may occur. Iron and sometimes manganese deficiency occur in badly drained, poorly aerated, soils and iron deficiency may be severe in such soils when they are also neutral or alkaline in reaction.

It is probable that the best corrective treatment for nursery material is to apply fairly liberal dressings of farmyard manure supplemented by small periodic applications of artificial fertilizer. For rapid improvement of nursery trees deficient in iron, spraying with 1 per cent. iron sulphate produces a quick response ; for the correction of manganese and copper deficiency, spraying with 0.5 per cent. manganese sulphate and with Bordeaux mixture respectively is satisfactory. When climatic conditions are unsuitable for nitrogen uptake, a quick improvement in nitrogen deficient leaves may be obtained by spraying with 1 to 2 per cent. Urea.

A condition analogous to nitrogen deficiency may be brought about by over exposure to sunlight : in this case the leaves may be high in total nitrogen but are very low in nitrate and are yellowish in appearance. Such a condition can be corrected by proper shade and adequate nitrogen fertilization.

The importance of mineral deficiencies in cacao propagation lies in the more rapid deterioration of mineral deficient leaves in the propagation beds.

As stated in a previous section, difficulties experienced in the rooting of the so-called difficult rooting clones were due primarily to deterioration and loss of leaves rather than to any instrinsic failure to root. When other conditions such as light intensity, temperature and the air-water relations of the rooting media were correct it was shown that deterioration of the leaves was due to unsatisfactory mineral nutrition of the leaves. In the present work nitrogen and iron were the two elements found most frequently to be

responsible for deterioration in the condition of the cuttings. In the case of iron deficiency response to iron was localized to the region of the leaf which was supplied with iron. When restricted areas of iron deficient leaves were treated with 1 per cent. ferrous sulphate these parts of the leaves remained green and healthy in the propagation chambers when the rest of the leaf had become yellow.

The interveinal injection technique described by Roach (1938) was found useful in diagnosing deficiencies in the nursery but after some experience of the symptoms it was relatively easy to diagnose the condition of nursery plants from visual symptoms.

The correction of mineral deficiencies in the nursery and the maintenance of correct shade has resulted in marked improvement in the condition of the cuttings during rooting.

(c) *General procedure for the rooting of single-leaf cuttings*

The most suitable material for single leaf cuttings are leaves from a recently matured flush in which the leaves have attained their full green colour but in which the stem is still green but hard. Flushes on healthy cacao plants attain a full green very quickly. Where the plants are deficient in minerals production of a full green colour takes a considerably longer time owing to the low rate of supply of the minerals concerned. By the time the leaves are full green the material may well be past its prime in-so-far as rapid root production is concerned : if, on the contrary, the cuttings are taken before they have reached a full green colour deterioration of leaves whilst in the propagation chambers may result. It is for these reasons that healthy nursery material is an essential condition for successful vegetative propagation of cacao.

The writer is indebted to Professor G. Stahel for details of a pruning technique which results in an abundance of suitable shoots for the preparation of leaf cuttings. Instead of utilizing all the leaves suitable for leaf cuttings from a green flush two or three buds at the base of the green flush are left. Such buds sprout immediately and give rise to new shoots. The pruning technique utilizes the fact that young buds on the green flush have not yet entered into the state of dormancy into which they later go when the stem becomes brown in colour. The production of suitable leaves is thus greatly hastened. With the resulting increase in the number of flushes the size of the leaf decreases but normal cacao leaves are in any case too large for use as leaf cuttings and are cut to a length of 6 to 7 inches—the smaller leaves do not need to be cut.

In the preparation of the cuttings the terminal bud is discarded and the stem cut $\frac{1}{4}$ inch above each node leaving a portion of stem below the node of 1 to $1\frac{1}{2}$ inches. If the laminae of the leaves are longer than 6 to 7 inches they are cut to this length in order to avoid excessive mutual shading of the cuttings in the rooting beds. The base of the cutting is dipped for about $\frac{1}{4}$ inch into the solution of growth substance. In the event of there being a risk of fungal infection the leaves may be dipped in Bordeaux mixture.

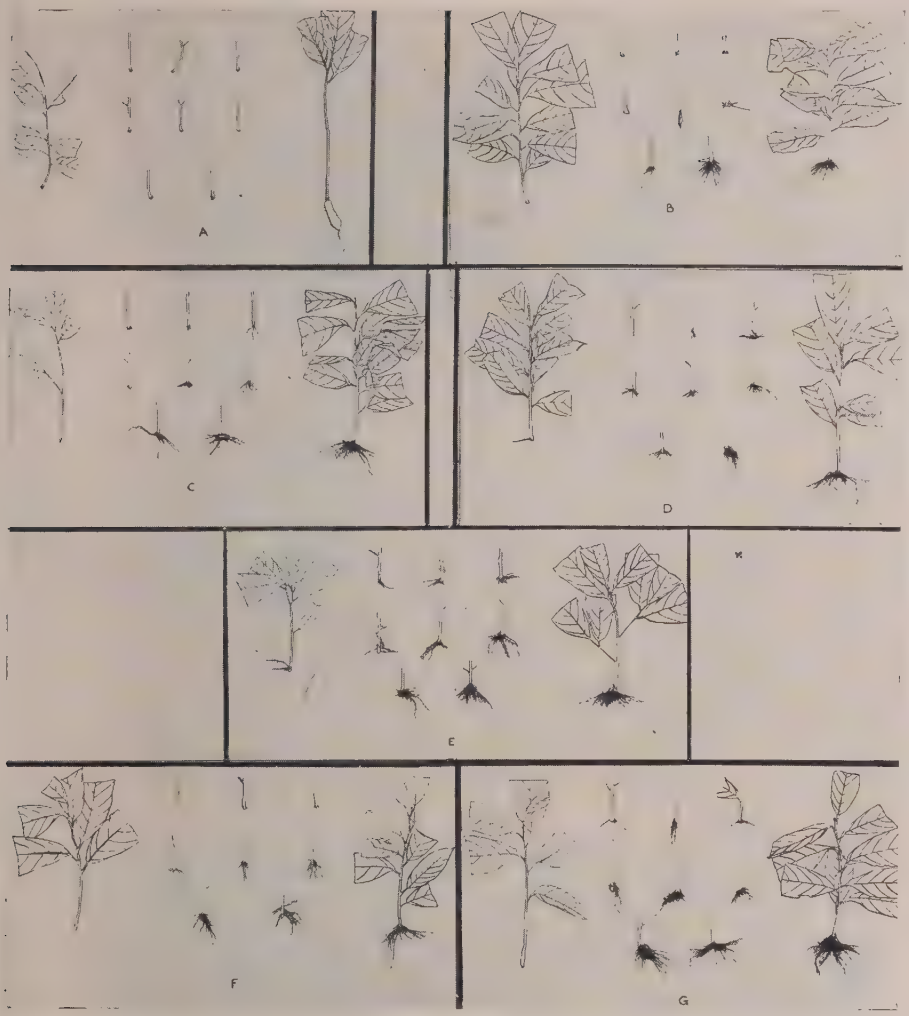


Plate 1.—Showing influence of treatment with growth substances and supplementary nutrients on rooting in the slow rooting clones ICS 56 and ICS 55. The range of rooting response is shown for each treatment. Cuttings were arranged at random in the propagators. Drawn from photographs taken 24 days after striking.

A—ICS. 56. No treatment

B—ICS. 56. Treated with growth substances (α NA + β IB).

C—ICS. 56. Treated with growth substances + 3 per cent. Sucrose.

D—ICS. 56. Treated with growth substances + 3 per cent. Sucrose + 200 ppm Arginine.

E—ICS. 56. Treated with growth substances + 3 per cent. Sucrose + 200 ppm Arginine + 200 ppm manganese sulphate + 1 ppm Vitamin B 1.

F—ICS. 55. Treated with growth substances only.

G—ICS. 55. Treated as in 'E' above.

Plate 3B.—Leaves of Theobroma cacao rooted from the petioles (no stem tissue attached).

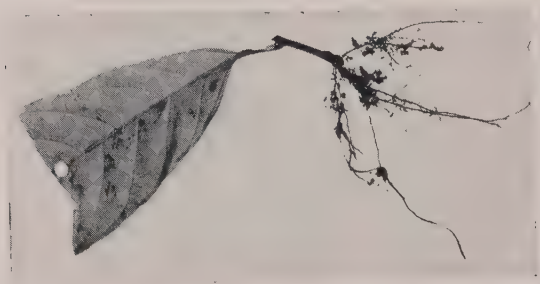


Plate 3A.—Root system of single leaf cutting (after hardening *in situ*) at time of potting.

Plate 2.—Showing method of supporting single leaf cuttings in the rooting medium.

Plate 5.—Leaf cutting (from leaf of fan shoot) at 4-5 months old.

Plate 4.—Single leaf cutting showing first stage in the growth of the shoot.

Plate 7.—Chupon (left) and fan (right) leaf cuttings ready for field planting at 8 months old.

Plate 6.—Leaf cutting (from leaf of chupon shoot) at 4-5 months old.

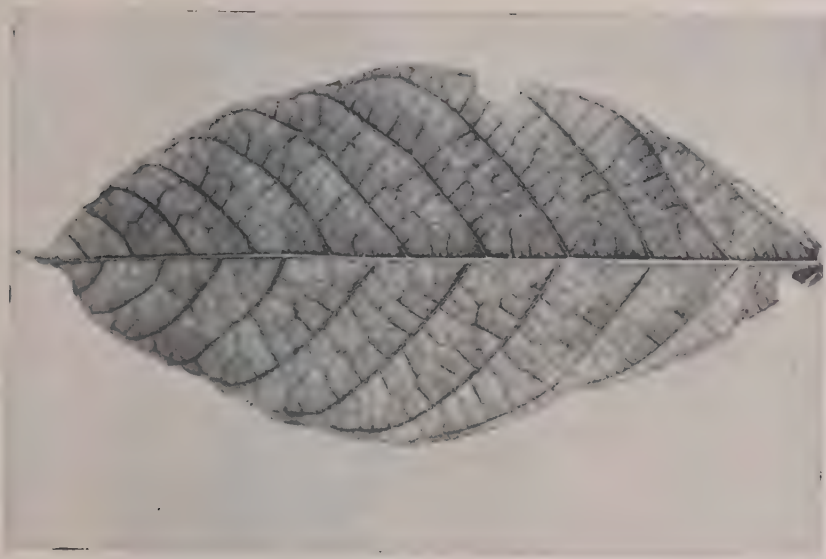


Plate 8B.—Leaf showing mild iron deficiency symptoms

Plate 8A.—Rooted cacao cutting showing acute deficiency of iron

Plate 10.—Open-sided greenhouse for temporary storage of rooted plants.

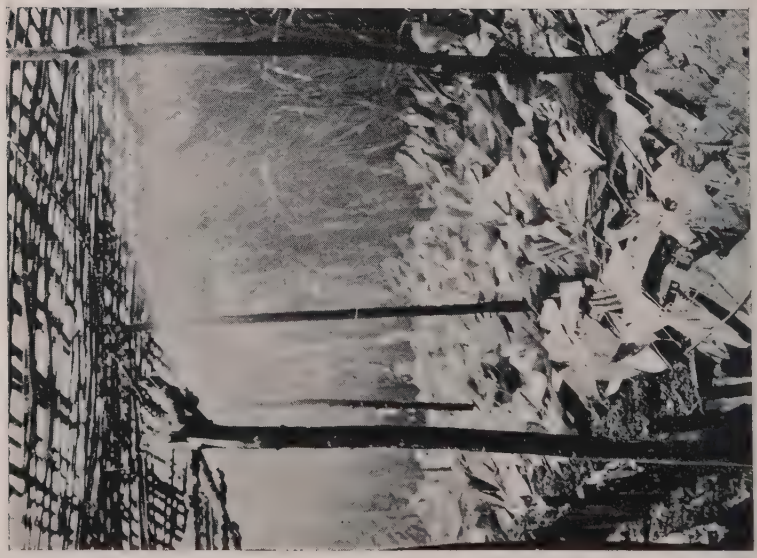


Plate 9.—Showing arrangement of Tee-jet nozzles in outside spray beds.

Plate 11A.—Bench-grafted rooted cacao cutting.

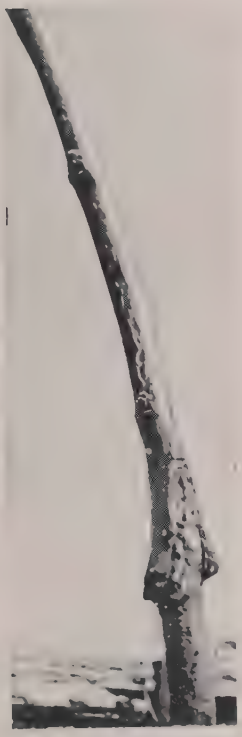


Plate 11B.—Close-up of graft union of plant shown in Plate 11A

Plate 12.—Typical rooting results after three weeks in cuttings of ICS. 95 from nursery grown under following light intensities from top to bottom: 15 per cent. light, 25 per cent. light, 50 per cent. light, 75 per cent. light, 100 per cent. light. Similar results were obtained with ICS. 1 and ICS. 60.

The method of supporting the cuttings in the rooting media is substantially the same as that used by Stahel (*see* Plate 2). Parallel iron rods or thick wire painted with black asphaltum paint are fitted into slots or between nails driven into wooden side supports. The slots or nails are arranged in pairs about $\frac{1}{4}$ inch apart with about 4 inches between each pair of rods and the rods are located about 3 inches above the surface of the rooting medium. The leaf cuttings are supported between each pair of rods, the $\frac{1}{4}$ inch space between the rods being sufficient to prevent excessive pressure on the laminae.

When striking the cuttings, the rods are inserted one pair at a time starting from the back of the propagating chamber and the stem portion is pulled forward about 2 inches before inserting it into the rooting medium thus giving the lamina a backward slant. This has the advantage not only of maintaining a humid atmosphere at the under surface of the leaf and exposing the lamina more effectively to the incident light but also holds the lamina more firmly and prevents lateral slipping.

The light requirement during rooting is the same for single leaf cuttings as for stem cuttings. The best rooting media are composted sawdust and vermiculite with the appropriate watering schedules for these media. These media are considerably better than coarse sand such as Toco sand although the latter will give reasonably satisfactory results with frequent watering.

Using the technique described above the rooting of single leaf cuttings is at least as satisfactory as stem cuttings, a rooting percentage of 95 to 100 per cent. being consistently achieved three weeks after striking the cuttings.

Stahel's method of supporting leaf cuttings after potting was found to be quite effective. (*See* Plate 4). Wooden stakes of white pine or other suitable wood are prepared beforehand and a thin nail driven through. The lamina of the leaf is impaled on the nail and a small piece of soft wood pressed on to the pointed end of the nail. Where suitable wood for stakes is in short supply the stakes can be used over and over again by impregnating with copper naphthenate or other wood preservative, drying and dipping into molten paraffin wax. A successful alternative method suggested by H. A. Williams of the St. Lucia propagating station, is to use sharply pointed stakes or skewers which are pushed into the rooting mixture and then lifted slightly so as to impale the lamina, the leaf is firmly held by this simple means. Bamboo sticks can also be used if this preservative treatment is first applied otherwise there is danger of fungal infection of the cacao leaf blade from pathogenic organisms carried on untreated bamboo sticks. The development of the single leaf cutting is shown in Plates 3 to 7.

(*d*) *The rooting of cacao cuttings in open beds under continuous spray*

As far as the writer is aware the first attempts to root cacao cuttings in open spray beds were first made at the Imperial College of Tropical Agriculture, Trinidad, by Spencer (1936). The method did not apparently give satisfactory results and little further work was carried out until Phillis

(1949) in Trinidad and Bowman (1948) in Costa Rica made further attempts to utilize this technique. Both Phillis and Bowman apparently had satisfactory rooting results but severe losses resulted when the rooted plants were hardened-off. In 1949, Constable at the La Pastora propagation centre, Trinidad, and the writer at Imperial College of Tropical Agriculture utilized the method. Using Skinner nozzles on a water line, coarse Toco sand as a rooting medium and camouflage netting as overhead shade Constable obtained extremely good rooting and has produced some tens of thousands of rooted plants by this method. Hardening-off was effected in the orthodox manner in hardening-off chambers. The method is now in use to supplement closed bin propagation at La Pastora. The writer's earlier experiments were carried out with an improvised watering system using nozzles from knapsack sprayers mounted on a water line. The set-up was rather small but was utilized to investigate the effect of light intensity and rate of fall of water on the rooting response. Later, a larger bed was erected using locally manufactured spray nozzles : these were in due course replaced by Skinner nozzles of the type used by Constable. Although valuable experience and data on the effect of external conditions were obtained in this preliminary work, water supplies both as regards quantity and pressure were insufficient to operate Skinner nozzles effectively. These nozzles consume one gallon of water per minute at the ordinary pressure of public water supplies. Ample supplies of cheap water at a pressure of about 40 lb. per square inch are necessary effectively to operate Skinner nozzles. Finally the Skinner nozzles were replaced by Tee-jet nozzles—originally manufactured for low pressure, low volume spraying of herbicides. These nozzles, manufactured by Spraying Systems Ltd. of Chicago, Illinois, and now manufactured under licence by Pest Control Ltd. of Cambridge, England, were found to be the ideal solution to the rooting of cacao stem cuttings under continuous spray. Varying nozzle apertures are available resulting in a water consumption of approximately from 2 to 7 gallons per hour per nozzle. Their outstanding advantage is that they are capable of operating efficiently under low as well as under high pressure, and that the area covered remains substantially the same over a considerable range of pressures—the volume of water per unit area only, rising with rising pressure. Water consumption is also low as compared to other types of nozzles.

The arrangement of Tee-jet nozzles is shown in Plate 9.

Before the Tee-jet nozzles had become available, the relationship between rooting medium and rate of fall of water per unit area was investigated. Strictly quantitative experiments on the rate of water-fall were not possible because of the variations in the water pressure. However, optimum rooting in a fairly fine sharp sand (known locally as Caroni sharp sand) occurred with a rate of water-fall of 1.5–2 cms. per hour ; for Toco sand, with a rate of 4–6 cms. per hour and a sifted coarse river sand fraction (particle size 1–2 mm.), 6–8 cms. per hour. It was noted also that for any particular type of sand, the range over which rooting took place was narrower, the finer the sand. In practice it was difficult to maintain rates below 1.5–2.0 cms. per hour because during periods of low pressure extra water had to be applied to prevent the leaves from drying out.

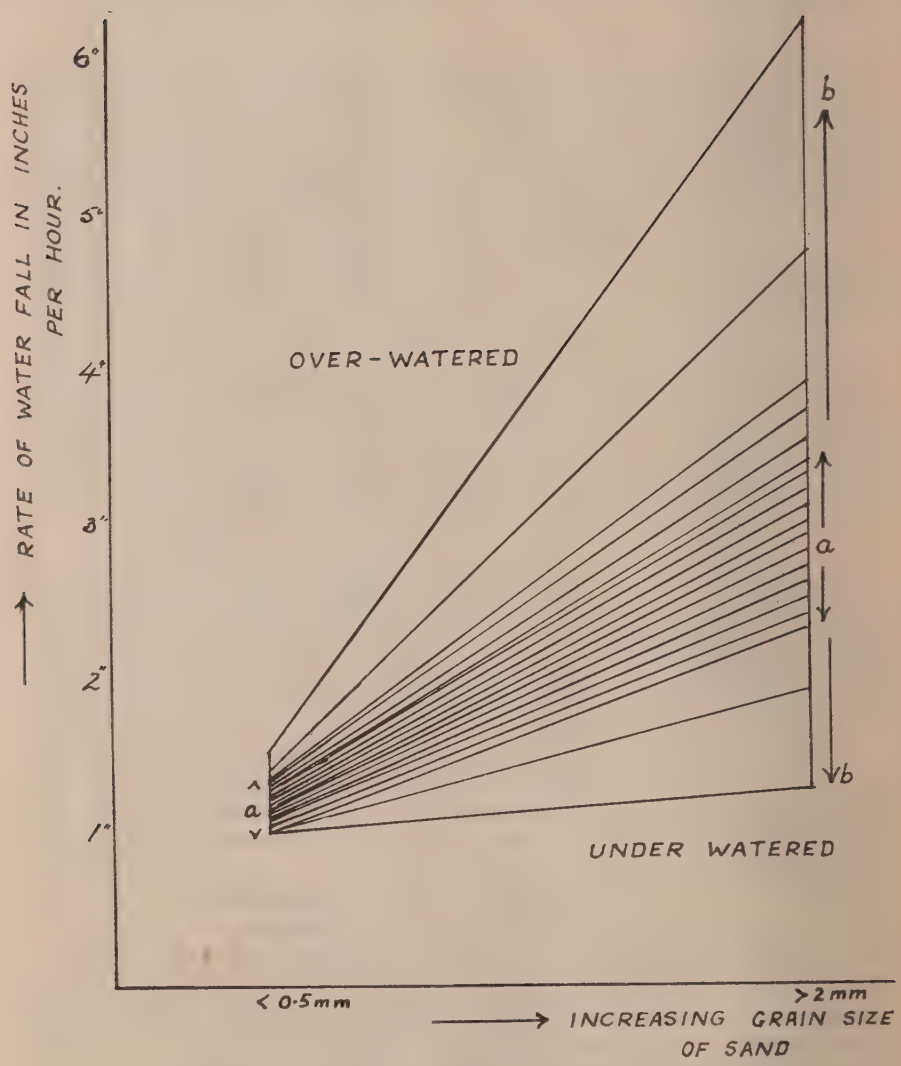
A diagrammatic representation of the results with different grades of sand is shown in Text-fig. 3. These results apply to sand and probably to other non-porous materials. They would not, however, apply to porous materials retaining a large volume of air within the particles, e.g. vermiculite. The latter was very effective as a rooting medium over a wide range of rates of water fall.

When the Tee-jet nozzles were installed tests of rooting media were made using Toco sand, composted sawdust, and a mixture in equal parts of composted sawdust and sand. By far the best results were obtained with composted sawdust and the poorest results in Toco sand. In sawdust compost cuttings of ICS 60 were ready to pot out and had excellent roots after 17 days and ICS 1 and ICS 95 after 22 days. The percentage final rooting varied from 90 per cent. in Toco sand to 98 per cent. in composted sawdust. The roots were far more numerous and more branched in the sawdust and this enabled the cuttings to be potted out one week sooner than those in Toco sand.

After being used for the rooting of one batch of cuttings the physical condition of the sawdust compost had deteriorated appreciably and subsequent rooting in the same compost was somewhat lower than Toco sand. It has already been shown that in closed propagators sawdust compost requires very light watering to produce optimum rooting. Nevertheless, if it is taken from the compost heap earlier (after 3 to 4 months) it may be used for about 3 batches of cuttings providing that drainage is completely free.

In the search for a more permanent rooting medium for open spray propagation various grades of vermiculite and slate wool were tested. All grades of vermiculite proved to be excellent rooting media under external spray propagation but the best results were obtained from the coarse grades. 100 per cent. rooting of a varied selection of clones occurred in 20 to 24 days.

Slate wool was better than Toco sand but was inferior to the coarse grades of vermiculite particularly with respect to the length and degree of branching of the roots. The coarsest grades of vermiculite represent the best rooting medium for open spray beds but freight rates on the material are high owing to its bulky nature, and results in a high landed cost. It may, therefore, prove to be necessary to use locally available material in spite of the fact that such material may be somewhat less satisfactory. Alternatively, it may be found economic to use a bed consisting of layers of stone, gravel, coarse sand and vermiculite—using the latter as the top layer 3 to 4 inches in depth. In the event of sand being the only material available, it is important that the sand should be of relatively uniform grain size to prevent packing and the actual grain size which is optimal is dependent on the rate of fall of water from the nozzles used. In sand the best results were obtained when the cuttings were planted fairly deep, providing that drainage was completely free. Sand is not suitable where the water supply is highly calcareous as it slowly cakes into a material resembling concrete. Under these conditions composted sawdust, composted coffee husks, shredded coconut fibre or rotten Immortelle wood may be used as rooting media. Such media will only give good results under a very light spray such as that produced by Tee-jet nozzles and must be changed as decomposition destroys their



TEXT FIGURE 3

Diagramatic representation of relationship between grade of sand and rate of fall of water in open spray bed. (*a*)—optimum conditions for rapid rooting; delayed rooting toward (*b*); little or no rooting beyond (*b*).

physical structure. Of these alternative media, fresh coffee husks contain a poisonous substance which will kill the cuttings in a few days : this substance was completely decomposed by 5 weeks composting. Such composted coffee husks gives good rooting results only for a maximum of two batches of cuttings, decomposition being so active that it deteriorates rapidly as a rooting medium. Shredded coconut fibre is never as good as composted sawdust though it may be used when supplies of the latter are not available. Rotted Immortelle wood is also inferior to sawdust compost but may be used as a substitute with reasonably satisfactory results.

The limitations of media for open spray propagation have been to a considerable extent overcome by the use of a double medium, as suggested above for vermiculite. In this procedure the basis of the bed is a layer of free draining sand on gravel. On top of the sand is placed a layer about 3 to 4 inches thick of composted sawdust or alternative organic rooting medium, or vermiculite if this is available. Cuttings are placed in the bed to such depth that the base of the cutting is located at or within half an inch or so of the interface between the organic layer and the sand.

This arrangement affords a compromise between excessive aeration in the sand and defective drainage of organic rooting media under a continuous spray. It enables organic rooting media to be used for longer periods and experiments have shown that excellent rooting is obtained when the material is in too advanced a stage of decomposition to be used as a rooting medium alone.

An alternative method of improving the drainage of organic rooting media under continuous spray was found to give satisfactory results. In this method a 6 to 8 inch bed of the stems of elephant grass (stripped of leaves) or thin bamboo (½ inch diameter) was laid by placing the layer of sticks at right angles to the previous layer until the necessary thickness is achieved. A layer of composted sawdust 3 to 4 inches thick is then laid on top and cuttings are planted to such depth that the base of the cutting is in the interface between the sticks and the sawdust, or even penetrating slightly into the layer of sticks. A comparison of this type of bed with one composed solely of sawdust compost using approximately 600 cuttings gave the following results.

Compost	% cuttings well rooted after 3 weeks	% cuttings lightly rooted	% cuttings not rooted
Sawdust compost on elephant grass stems	79	21	0
Sawdust compost alone ...	75	15	10

Both the modifications in the construction of the bed described above were very considerably better than mixing sawdust compost and sand. In this case the sawdust compost appears to block the spaces between the sand particles and results were generally unsatisfactory.

(*e*) *Effect of light intensity under conditions of spray bed propagation*

Since in the open spray technique the complicating effect of temperature was absent owing to the cooling effect of water falling continuously on the leaves, this method afforded a useful method of testing the direct effect of light. Rooting actually occurred at all light intensities from 10 per cent. to 100 per cent. sunlight. In full sunlight, however, under these moist conditions active decomposition of chlorophyll took place resulting after 3 to 4 weeks in extensive bleaching of the leaves. The bleached areas were very susceptible to attack by micro-organisms and subsequent losses in hardening were high. A reduction of the light intensity to 75 per cent. of full sunlight prevented bleaching but decomposition of chlorophyll resulting in paling of the leaves was still active. With decreasing light intensity the effect on chlorophyll decomposition decreased steadily without any detrimental effect on root production.

Excellent rooting has been obtained with a light intensity of 25 per cent. of full sunlight. At 15 per cent. sunlight rooting was satisfactory but there was a small loss of cuttings due to starvation caused by mutual shading of the cuttings.

Approximately 25 per cent. of sunlight is optimal for rooting in open spray beds assuming that cuttings are placed in a mozaic pattern so that each cutting is exposed to the incident light. This result does not agree with the statement of Bowman (1948) who recommended full sunlight on the spray beds. The explanation is probably partly that in Bowman's method the cuttings were very closely packed so that, in fact, a relatively small proportion of the leaf area was under exposure to full sunlight. On the other hand Bowman experienced difficulties in hardening plants rooted under open spray. This may well have been due to deterioration in the condition of the cuttings under excessive light.

(*f*) *Leaching of nutrients from cuttings whilst in the spray beds*

Before high light intensity was recognised as the factor responsible for paling of the leaves, it was considered that loss of colour might be due to leaching of nutrients from the leaves. An experiment to test this possibility was carried out. Single leaf cuttings were planted and three samples each of 20 cuttings were analysed (*a*) at planting (*b*) after 2 weeks under the spray (*c*) after one month under the spray. The analytical results (analyses were carried out by the College Chemistry Department) are summarized in Table XVII.

The results indicate that nitrogen, potash and phosphate were leached out of the leaves : loss of nitrogen and phosphate was mostly confined to the first two weeks, whilst loss of potash was continuous during the whole rooting period. At one month the cuttings had a good root system and it is probable that the decreased loss or recovery of minerals during the last two weeks was due to uptake by the roots. Such losses of nutrients as occurred in this experiment were not sufficient to affect the condition of the rooted plants and samples of the same cuttings were established without difficulty.

TABLE XVII

Sample		% Oven-dry material				% of Ash		
		Ash	Nitrogen	P_2O_5	K_2O	Nitrogen	P_2O_5	K_2O
(*a*) at planting	(1)	6.80	2.02	0.60	2.35	29.7	8.83	34·56
	(2)	6.92	2.00	0.55	2.42	28.9	7.93	34.96
	(3)	7.88	2.09	0.72	2.34	26.5	9.13	29.68
	Mean	7.20	2.04	0.62	2.37	28.3	8.63	33.07
(*b*) after 2 weeks	(1)	6.89	1.90	0.44	1.94	27.5	6.39	28.15
	(2)	6.59	1.84	0.43	2.02	27.8	6.52	30.65
	(3)	6.72	1.89	0.47	2.22	28.1	7.10	30.06
	Mean	6.70	1.88	0.45	2.06	27.8	6.67	30.62
(*c*) after 1 month	(1)	8.49	1.86	0.54	1.91	21.9	6.36	22.50
	(2)	7.73	1.80	0.51	1.88	23.3	6.60	24.32
	Mean	8.11	1.83	0.53	1.90	22.6	6.48	23.41

It is obviously, however, a factor which should be reduced to the minimum and accordingly it is advantageous from every point of view to utilize the minimum amount of water compatible with keeping the leaves wet and cool.

(*g*) *Special features associated with the rooting of single leaf cuttings in open spray beds*

Stem cuttings were placed in the spray beds at an angle of 30°–40° and most of the water falling on the leaves dripped off without flowing to the basal part of the stem. In the case of single leaf cuttings most of the water falling on the lamina was channelled downwards along the midrib and flowed into the rooting bed in the vicinity of the stem portion of the cutting. This resulted in too high water and low aeration at the base of the cutting and initiation and emergence of roots was thereby delayed. This was particularly the case in sawdust compost and occurred to a lesser extent in Toco sand. Generally only 60 to 70 per cent. rooting occurred after one month whereas in closed propagators 90-100 per cent. rooting occurred in three weeks.

Various modifications of procedure were tried including placing a calico cloth canopy immediately above the cuttings so that the water fell on the cloth and was diverted away from the beds. Under these conditions the cuttings dried out : periodic wetting of the leaves proved to be essential even when the cloth canopy was placed as close as possible to the cuttings.

Single leaf cuttings rooted well under continuous spray when the volume of water falling on the leaf was reduced. This was achieved by the use of a Bahnson Centrifugal humidifier.

It is possible to achieve low volume spraying with suitable Tee-jet or other low volume nozzles but it is generally essential to have a high water pressure. Alternative methods have been described by O'Rourke (1949) including a very efficient atomizer requiring a water pressure of 70 to 80 lb.

per square inch. Air-water type nozzles require an air-compressor to atomize the water. Such equipment is not normally available nor feasible in cacao plantations where much of the propagation work may be carried out, although it might be feasible in large propagating stations.

The pressure of the water supply for the present work fluctuated greatly and was often as low as 5 to 10 lbs. per square inch during the hottest hours of the day. It was, therefore, imperative to use relatively coarse (O.C. 02 Tee-jet nozzles) in order to obtain adequate coverage at times when the water pressure was low.

A large scale experiment on the rooting of single leaf cuttings under continuous spray using different rooting media gave the following percentage rooting after 25 days.

Medium	*% rooting of single leaf cuttings*
Slate wool	86
Rotten Immortelle	60
Fine grain Vermiculite	51
Medium grain Vermiculite...	66
Coarse grain Vermiculite	81
'Exflor' Vermiculite	93
Fresh composted coffee husks	75
St. Lucia quartz crystals (a coarse silica sand)	95

The organic rooting media and the vermiculite deteriorated with use owing to decomposition and loss of structure in the former and collapse of the micaceous plates leading to packing and defective aeration in the latter.

The slate wool and the quartz crystals were not affected by use.

It has been established that single leaf cuttings may be rooted satisfactorily under open spray providing that the medium is exceptionally free draining—much more so than is necessary for stem cuttings. Quartz sand of a mean particle size of 2.0–2.5 mms. provides a satisfactory medium. These remarks apply to relatively large aperture Tee-jet nozzles necessary under conditions of low water pressure. In the event of higher water pressures (approximately 50 lbs. per square inch) enabling the use of finer Tee-jet nozzles being available a wider range of rooting media, such as those used for stem cuttings may be used satisfactorily.

(h) General conclusions on the rooting of cacao in open spray beds

It has been emphasized that when light and temperature conditions are optimal and the nursery material satisfactory, the chief factor controlling rapidity and degree of rooting is the air-water relations of the rooting medium. In closed propagators the water applications can be strictly controlled both as regards frequency of application and amount applied. This enables the use of a fairly wide selection of rooting media for closed bin propagation.

In open spray propagation, the control of the water supply is largely an engineering problem and theoretically is also subject to complete control. In practice, however, unless relatively expensive equipment—such as booster pumps or air compressors or electrically driven humidifiers are available,

the best use has to be made of the water supply available. Given the characteristics of the water supply system it is possible to select nozzles to provide the lightest possible spray consistent with the greatest adequate coverage. Having achieved this, no further control of the water supply is possible and any further control of the air-water relations of the rooting medium can only be achieved by selection of the medium itself.

The best media of easily available materials for use in the rooting of stem cuttings and of single leaf cuttings have been described above. In all cases too much emphasis cannot be laid on the necessity for completely free drainage of the beds. With normal mozaic pattern placement of the cuttings the optimum light intensity approximates 25 per cent. of full daylight. If an ample supply of cuttings is available and the percentage of successful rooting is not a primary consideration, the cuttings may be spaced more closely in which case a higher light intensity may be allowed.

Under continuous spray considerable leaching of mineral substances and of soluble organic compounds from the leaves may occur. Unless the cuttings are in prime condition deterioration in the condition of the leaves may occur if rooting is not complete by the end of 28 days. This in itself would only be the case if the conditions were suboptimal.

In the present experiments it has been established that under optimal conditions rooting of the quicker rooting clones is sufficiently advanced to pot out after 17 to 18 days and of the slower rooting clones in 20 to 24 days.

Results from open spray beds may thus be comparable to those achieved in closed propagators when the conditions in both are optimal.

9. *The Hardening-off Procedure for Rooted Cacao Cuttings*

(*a*) *Modification of the usual hardening procedure*

Rooted cacao cuttings need to be "hardened" before exposure to normal atmospheric conditions. The usual procedure is to place the plants immediately after potting in hardening-off chambers similar in construction to the propagation chambers except that they are not so deep. Generally the plants are well watered when placed in the chambers but no further watering is given and the hardening chamber covers are closed for a period of about 14 days and then gradually lifted a few inches at first and more rapidly later. The whole process may well take from 2 to 3 weeks.

A study of the hardening process showed that two distinct phases were involved. The root system of the rooted cutting was quite inadequate to supply transpirational requirements of the leaves. The first phase of the hardening process involved the production of a root system with an absorbing surface adequate to supply the requirements of the shoot. The second phase was to acclimatize the cutting which had been in a more or less saturated atmosphere for some weeks to the lower humidity of the outside atmosphere. Of these two phases the first was shown to be by far the most important.

Root development was most rapid under conditions of high moisture providing that aeration in the medium was adequate. Contrary to the usual procedure the potted cuttings were watered twice a day for the first 6 days with the covers closed. By this time root tips were emerging from the baskets.

During the next two days the covers are raised about 2 inches followed by two days with the covers raised to 8 inches and two days with the covers raised to 18 inches. After a total of 12 days the plants were placed in a cool open-sided greenhouse. Watering twice a day was carried out throughout the hardening process. The hardening chambers permitted about 20 per cent. of sunlight to reach the cuttings.

(*b*) *Hardening rooted plants in situ*

Cuttings rooted in composted sawdust developed a well branched root system. Since the medium was particularly suitable for root growth, experiments were carried out on the possibility of hardening the plants in the rooting bin prior to potting out. Mr. Ake Burchardt of the Hacienda Clementina, Ecuador, informed the writer that he had adopted hardening *in situ* with successful results and that all the hardening bins were used as propagators with greatly increased output of rooted plants. The rooting and hardening technique has since been published (Burchardt and Jorgensen 1950).

The writer's experiments showed that hardening *in situ* was particularly satisfactory when cuttings were rooted in sawdust compost or similar vegetable material or in vermiculite. When rooting had occurred the propagator covers were slowly raised, two inches for the first two days, four inches for the next two days, eight inches for the following two days and fifteen inches for the next two days. The plants were then potted out or transplanted into beds disturbing the root system as little as possible by removing some of the rooting medium with the roots. During hardening the same watering schedule was adhered to as that used for rooting the cuttings, i.e., three light waterings per day. With optimal conditions for rooting, this procedure took 30 to 35 days for producing rooted and hardened plants. After potting or transplanting into beds the plants were given three light waterings per day for the first 2 to 3 days.

The method was particularly suitable for single-leaf cuttings. Owing to the greater number of leaf cuttings which can be rooted in the propagators and the fact that each leaf cutting would require the same space in the hardeners as stem cuttings, the demand for hardening chambers for single leaf cuttings would normally be very considerable. With this technique, however, no hardening bins are required and the propagator chambers are only in use for 8–10 days longer than the normal period for rooting.

The root system of a single leaf cutting after hardening by this method is shown in Plate 3A. The procedure is undoubtedly a great advance on previous technique.

(*c*) *Hardening-off cuttings rooted in outside beds under mist spray*

In order to reap the full benefits of the large scale production of rooted cuttings in open spray beds, it is obviously necessary to evolve a similar large scale method of hardening the rooted plants. That this was possible was shown in preliminary work using very fine humidifying nozzles normally used for greenhouse humidification. The spray produced by Tee-jets used

for rooting was not suitable for hardening since (*a*) prolonged leaching of materials from the leaves for a further period after rooting resulted in a deterioration in the condition of the rooted cuttings, (*b*) the spray results in an over-watering of the potting mixture. What was required was equipment capable of producing an almost saturated atmosphere with the expenditure of a minimum amount of water. To accomplish this a Bahnson Centrifugal humidifier has been successfully used.

A glass house was constructed using spare glass frames for the sides and calico cloth nailed on to wooden slats for the roof. The potted cuttings were placed in tiers in this hardening-house—with a house 9 feet high it was possible to place 4 tiers of potted cuttings. This temporary structure accommodated approximately 600 plants. The centrifugal humidifier was placed at one end at a height of approximately 6 feet. No plants were put directly in front of the humidifier. In the preliminary experiments use was made of a paper humidistat by means of which the humidity could be controlled through tension on a spring operating a water valve. Later it was found more convenient to remove the humidistat and to keep the valve fully open with wire. The humidifier was kept on continuously during the day for the first 6 days and was then operated for 1 to 2 minutes every half hour except for the hottest period of the day, when it was kept on almost continuously, for the next 3 days. The plants were then removed and placed in a cool greenhouse. Root development under these conditions is extremely rapid—roots emerge out of the baskets in 4 to 5 days and within 8 to 9 days the root system is adequate to provide the water requirements of the shoot. The hardening procedure is thus completed in 10 days and practically no losses of plants has occurred. The humidifier was capable of maintaining 100 per cent. humidity in a larger house than that used for these experiments and there was little doubt that up to 3,000 plants could be hardened in each batch.

By staggering the planting of cuttings at intervals of 10 days it was possible to keep the humidifier in continuous operation for hardening the rooted cuttings.

10. *Evaluation of Methods of Propagation*

(*a*) *Large or medium scale methods*

Three alternatives for large or medium scale propagation of cacao are now available, viz. (i) a large number of closed propagators and a balanced number of orthodox hardeners. Stem cuttings are rooted and hardened by the usual method. (ii) Closed propagators using composted sawdust or vermiculite as rooting medium and using stem or single leaf cuttings which are subsequently hardened in the rooting bins. (iii) Rooting under continuous mist spray and hardening in a new type hardening house using a Centrifugal humidifier or similar equipment capable of maintaining 100 per cent. humidity.

It is considered that the first of these three methods can no longer be considered economic. The choice between the second and third methods would be affected by various factors such as (*a*) the relative abundance of

nursery material and the degree of urgency of requirements of material for field planting. If plants ready for the field in 2 to 3 months were required and abundant nursery material were available, the choice would lie with stem cuttings. Contrariwise if rapid bulking of material was the prime consideration and plants for the field were not required for 7 to 8 months the choice would lie with leaf cuttings.

(*b*) Availability of abundant and cheap water supply and electric current to operate the humidifier would favour the third method whereas short supplies of water and/or non-availability of electric current would be factors in favour of using the second method. Consumption of electricity by the centrifugal humidifier is small as the electric motor is only ¼ H.P.

(*b*) *Small scale methods*

The very large demand for clonal material and the inconveniences and limitations of transporting rooted plants for considerable distances from large propagating stations suggests the desirability in certain circumstances of decentralising clonal propagation and to devise techniques for use by the individual planter. Prominence has been given recently to large box-type propagators in Costa Rica and Constable in Trinidad experimented with a bamboo structure lined with plastic cloth. Burchardt and Jorgensen (1950) have also used Jute cloth kept moist in place of the usual type of bin cover.

There is little doubt that once the basic requirements are known various improvisations may be resorted to. For small-scale propagation the writer considers that a propagator of wood, brick or other locally available material using sawdust compost, rotted Immortelle wood, shredded coconut fibre or similar material as rooting medium would be the cheapest. The height of the propagator should be 2½ to 3 feet, the width about the same, and the length would be dependent on the number of cuttings required. If the cover is to be of jute cloth—the cloth should be capable of being tightly stretched and have sufficient slope to prevent percolation of water during heavy rains leading to excessive watering of the medium and so resulting in delayed rooting. Choice of jute cloth is also of great importance. Light intensity under three types of jute sacking varied from 200 foot candles to 1,800 foot candles on a bright day according to the closeness of the weave. One type which transmitted 700 foot candles on a bright day gave excellent rooting results. Under the tightly woven jute cloth the cuttings starved and became yellow after 10 days, under the most loosely woven cloth there were indications of water deficit in spite of frequent moistening. Under the medium grade the cuttings remained green and healthy and rooted normally.

A preferable procedure is to have covers of plastic cloth over the bins and to use the jute cloth as an overhead shade. Under these conditions no calico is required over the plastic cloth.

The cuttings should be treated with root inducing growth substance at the correct concentration and should be hardened *in situ* by the method described in section 9 (*b*).

11. *The Composition of the Potting Mixture and After-Care of Rooted Cuttings*

(*a*) *Experiments on the merit of potting mixtures*

When the writer undertook the propagation investigations described in the preceding pages, it was noted that potted plants sooner or later commenced to show symptoms of malnutrition. The potting mixture was similar to that in current use at the College and consisted of one part soil, one part river sand and one part vegetable compost. The appearance of these symptoms was earlier in single leaf cuttings and in many clones the symptoms were acute even in leaves of the first flush. The leaves showed varying degrees of chlorosis and tip and marginal scorch : growth ceased or was considerably reduced. Using the interveinal injection technique developed by Roach the trouble was diagnosed as due mainly to iron deficiency and to a lesser degree to manganese and magnesium deficiency. This condition was traced to a high content of free calcium carbonate in the soil used and which together with slightly alkaline sand resulted in a potting mixture of pH 8.0–8.4. A further factor which was involved was poor aeration—there was a distinct amelioration in the condition of the cuttings by reduced watering. The symptoms were also accentuated under bright light and were less pronounced in the shade. The condition of the affected plants and the response to interveinal injection of iron are shown in Plate 8A. Mild iron deficiency symptoms are shown in Plate 8B.

In a search for a more favourable potting mixture which would be available in adequate quantity use was made of sawdust composted with farmyard manure for about nine months and a soil of pH 6-6.5 low in free calcium carbonate. Several experiments were carried out on the merits of different mixtures. Mixtures of slightly acid soil and sawdust compost were effective in preventing the appearance of deficiency symptoms of iron, manganese and magnesium but acute nitrogen deficiency symptoms soon showed up. It was clear that the sawdust compost resulted in a tying up of the soil nitrogen for a considerable period. Addition of dried blood and hoof and horn grist to the mixture of soil and sawdust compost resulted in healthy well nourished plants. As supplies of these supplements were not available locally, artificial fertilizers were used as substitutes.

The potting mixture finally adopted was 2 parts of slightly acid soil with 1 part of well composted sawdust. This mixture was fortified at the time of mixing with 4 ounces sulphate of ammonia, 2 ounces sulphate or muriate of potash and 1 ounce superphosphate to each bushel of the mixture. The fertilisers were intimately mixed or applied in solution. It was necessary to leave the mixture standing for a week or ten days before use : immediate use involved the risk of causing fertiliser scorch in the potted cuttings. Plants grown in this mixture still developed nitrogen deficiency symptoms but this was easily corrected by addition of 2 grams or so of sulphate of ammonia to each potted plant every three to four weeks or by periodic spraying with 1 per cent. Urea.

The mixture had the advantage of being easy to prepare, of providing a well aerated medium and contained adequate amounts of essential elements ensuring extremely healthy and rapid growth. Single leaf cuttings potted in this medium developed into plants ready for field planting in about

7 months. The use of sawdust compost enriched with horse manure lessened the requirement of periodic applications of sulphate of ammonia. The procedure which was found to result in most rapid decomposition of the sawdust when preparing sawdust compost was as follows : Sawdust and farmyard manure were mixed or layered in the proportion of 4 to 5 parts of sawdust to 1 part of manure. Between each layer of sawdust and manure a layer of fibrous material such as brush wood, elephant grass or Guatemala grass was incorporated to aid aeration. The heap was soaked with water and covered with a thatch of elephant grass or sugarcane trash to help to retain moisture. The heap was further watered during dry periods. After 4 to 5 months it was suitable for use as a rooting medium. When it had decomposed too far to be of further use as a rooting medium it was utilized in the potting mixture. Alternatively it could be left to rot for 9 to 10 months in the heap prior to being used in the potting mixture.

The necessity of providing a suitable potting mixture cannot be over emphasised particularly in the case of single leaf cuttings. The supplementary doses of nitrogenous fertiliser after potting is important where sawdust compost or similar organic material of high carbon/nitrogen ratio is used.

In the case of single leaf cuttings, the first flush from the axillary bud develops to a length of at least six inches in the first 5 to 6 weeks after potting. If nutrition was adequate a second flush was produced a week or two after the first flush matured. With inadequate nutrition there was an interval of several weeks between flushes and growth of the plants was correspondingly delayed.

Faulty nutrition of potted plants was shown to be one of the most important causes of losses after potting in Government and privately owned propagation stations in the Caribbean area visited by the writer.

In those stations where considerable care was taken in the preparation of the potting mixture and slightly acid mixtures rich in organic humus were used, mild or severe nitrogen deficiency symptoms were in evidence. In addition to slowing down the rate of growth of the cuttings, the effect of nitrogen deficiency and to a lesser extent deficiency of other mobile major elements may be more serious in newly potted plants in that with the formation of the first flush nitrogen is withdrawn from the older leaves which accordingly become yellow and senescent. This may occur before the flush has become photosynthetically self-supporting and, if all the leaves are involved, the cutting cannot survive. The same effect may occur as a result of inactivity of the root system due to unfavourable conditions for root growth in the potting medium. In this case the existing root system may be sufficient to supply the needs of the leaves originally present on the cutting but insufficient to supply the additional requirements of a vigorous flush of young leaves which transpire relatively actively. Water may accordingly be withdrawn from the older leaves resulting in yellowing and senescence of these leaves. Loss of the existing assimilating leaves leads to starvation of the young flush and consequent death of the rooted cutting.

Mr. G. Rodrigues of the Imperial College of Tropical Agriculture is of the opinion that, in Grenada, release of manganese in toxic quantities as a result of addition of organic matter may be the cause of an inducedir on deficiency in potted plants. In most of the smaller West Indian islands sawdust is not available : the soils may also differ considerably. In such cases use should be made of locally available organic material and simple experiments carried out on suitable potting mixtures.

(*b*) *Storage of potted plants*

Owing to the fact that field planting of young cacao plants may be confined to a few months in each year whilst propagation is in progress all through the year and also to the fact that rooted cuttings are generally too small to be planted directly in the field, it is generally necessary to have storage space for potted plants. It is a great advantage to have overhead protection for young plants against heavy rain. The usual type of structure in use for this purpose is an open sided greenhouse with roof consisting of alternating glass and galvanized iron or aluminium sheeting exposing the plants to 40 to 50 per cent. sunlight (*see* Plate 10). Such green houses are, however, expensive to construct and satisfactory results have been obtained with an overhead shade of wooden laths letting through the same proportion of sunlight. It is an advantage to use narrow laths in order to avoid excessive drip on the plants in heavy rain. When using a lath screen over young plants it is almost essential to spray the plants at intervals with Bordeaux mixture as a protection against Phytophthora attack particularly in areas of high rainfall.

12. *Some Observations on Grafting Technique in Cacao*

The method generally adopted for the grafting of cacao is the patch-bud method in which an oblong piece of scion bark, bearing a bud, is fitted into a corresponding area of the stock from which the stock bark has been removed. A modified form of this grafting method known as the inverted U graft has recently been claimed to give better results in Costa Rica.

The patch-bud method has given satisfactory results in grafting operations made under cover in Trinidad. The writer has found the modified method particularly suitable for field grafting on young chupons. This method was used for rapid multiplication of certain I.C.S. clonal material which was in short supply. Buds inserted on chupon shoots developing at the base of existing cacao trees make rapid growth and leaf cuttings are taken from the scion shoots after a few months, thus leading to rapid bulking up of material in short supply.

In the course of grafting experiments designed primarily for testing the effect of grafting quick rooting clones as scions on difficult rooting clones as stocks, a considerable number of bench grafts were made. The methods used were saddle grafts and wedge grafts of leaf bearing shoots in optimum condition for rooting. The saddle graft was preferred to the wedge graft owing to the reduced chances of water percolating into the graft during rooting.

An essential condition for a high percentage success is that the stock as well as the scion must bear healthy leaves in order that both stock and scion are supplied with carbohydrate during the rooting period before union of the tissues is complete. The leaves are cut back to one-third or one-half of their

original length as for stem cuttings. After making the graft the composite cutting is treated with growth substance and rooted in the propagators as in the case of normal stem cuttings. The graft union is tied with grafting tape and the additional precaution of painting the tape over with a low melting point paraffin wax seems to be worth while to avoid the possibility of percolation of water to the graft following the usual watering of the cuttings. From 80 to 90 per cent. of the saddle grafts were successful and were ready for potting in four weeks. A bench grafted cacao plant is shown in Plate 11(a) and the graft union in Plate 11(b). A small field experiment on stock scion effects was recently planted with 300 such bench grafted cacao plants and established without difficulty.

It is considered that bench grafting of cacao offers a practical alternative to the methods at present in use.

13. *Transport of rooted cacao cuttings*

Some experiments have recently been carried out on the transport overseas of rooted cacao cuttings. Sea and air transport was used. For sea transport the safest procedure is to plant cuttings in Wardian cases with windows and cover of plastic cloth. Wooden baffles are fitted to the bottom to avoid undue movement of the rooting medium and wire or string supports to hold the cuttings in a vertical position. Cuttings with a hardened flush are planted bare root 9 to 10 days before shipment in the Wardian cases using sterilized sawdust compost as rooting medium. Approximately 50 cuttings can be planted in such a case. The cases are placed on deck and watered occasionally during the voyage. If the cases are to be in full daylight, calico cloth should be placed over the plastic but it is preferable not to place the plants in full sunlight but to select a reasonably shaded part of the ship. Such cuttings keep without loss for periods of 1 month or more.

For air transport the roots of the cuttings are placed in small bags of hessian or jute cloth containing damp sterilized sawdust compost or pulped newspaper and the bags tied up around the stem. The cuttings are packed in cardboard cartons lined with waterproof or waxed paper.

Under these conditions the cuttings are in complete darkness during the period of transport and this sets a limit on the survival period. Under tropical temperatures the rate of respiration is such that all food reserves are exhausted and starvation and breakdown of the leaves commences after 4 to 5 days. About 90 per cent. establishment was obtained after this period but only 40 per cent. establishment after 6 days and there were no survivors after 8 to 9 days. It is thus necessary to ensure that the cuttings reach their destination and are planted out in hardeners with high humidity and suitable light intensity within 4 to 5 days of the date of despatch otherwise losses are high.

It is also necessary to ensure that the cuttings are not exposed to chilling temperatures *en route*. For very short trips (24 hours or less) the cuttings may be packed bare root with layers of wet newspaper between the cuttings in cardboard cartons. Providing that the plants are potted immediately, placed in chambers at 100 per cent. humidity, and hardened in the usual way a high percentage survival is obtained.

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AGRONOMIC CHARACTERISTICS OF SANSEVIERIA SPECIES [1]

By

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Summary

The species of sansevieria have been classified into three large inter-grading groups according to botanical characteristics of the leaf, the rhizome and the fibrous root system. Representative species of these three groups have been studied for their potentiality for fibre production in South Florida.

The cylindrical leaf species (group I) have been found unsatisfactory for commercial production because of their difficulty of propagation, slow rate of growth and low acre yield of fibre.

The coriaceous leaf species (group II) have shown some promise for annual harvesting because of their ability to produce a rapid growth of leaves when planted from rhizomes. Species of group II have the highest per cent. of fibre but have comparatively short leaves and are readily damaged by low temperatures.

The narrow or petiolar leaf species (group III) offer the best potentialities for production of fibre because of their ability to grow rapidly from leaf cuttings and their high yield of fibre per acre. Of the species in group III, *S. thyrsiflora* has the highest per cent. of fibre but is limited by its susceptibility to cold damage. *S. laurentii* has the greatest tolerance to cold, but is limited by its low per cent. of fibre. *S. trifasciata* has a satisfactory tolerence to cold, an intermediate per cent. of fibre and a good length of leaf. It appears to have the greatest potentiality for fibre production in South Florida.

The potentiality of sansevieria as a fibre crop has been recognized since early times. The plant was harvested in the wild by natives of Africa and the fibre used for making coarse fabrics, fish nets and bowstring. During the early part of the century, various attempts were made to harvest extensive acreages of wild growth in Africa but without commercial success (15). The peoples of India and Ceylon are reported to have cultivated *Sansevieria zeylanica* Willd. for local handicraft use but have never produced it in commercial quantities for export (13). More recent attempts have been made to cultivate the crop in Mexico, Cuba, the Bahamas and in South Florida (10, 12). The work reported herein is a preliminary part of studies undertaken during and since World War II to determine the suitability of different species for fibre production in South Florida.

(1) Studies of the Division of Cotton and Other Fibre Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U.S. Department of Agriculture, with the Division of Agricultural Engineering, Everglades Experiment Station and Mr. Oscar R. Winchester, Boynton, Florida, cooperating. Published with the approval of the Chief of the Bureau of Plant Industry, Soils and Agricultural Engineering and the Director of the Florida Everglades Experiment Station.

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The individual species of sansevieria show an extremely wide variation in growth, form and habitat. For example, *S. singularis* N. E. Br. which grows in the arid plateaux of central Africa has a solitary cylindrical leaf 7 to 9 feet in height, as compared to a species like *S. dooneri* N. E. Br. which has about 20 short lanceolate leaves in a tuft and grows in more humid regions. These variations in botanical structure affect the yield of fibre and the cultural characteristics of the plant. It is the purpose of this study to relate the botanical structure of the plant to the agronomy of fibre production.

Review of Literature

The genus Sansevieria as recognized today was described by Thunberg in 1794. Many of the early descriptions of species are not well defined. Seven of the more common fibre species are discussed in Kew Bulletin 5 (13) 1887. Gerome and Labroy (7) in 1903 described 20 of the more important fibre species and classified them according to the shape of leaf and certain other vegetative characteristics. Brown (2) in 1915 in a monograph of species gave 63 descriptions of which 54 were recognized. A number of new species have since been reported. However, there is some confusicn as to the description of certain species, and the names presented in this paper are therefore considered tentative until more detailed studies can be made.

A preliminary report on the culture of sansevieria is given in Kew Bulletin No. 5 (13) in 1887. Propagation by leaf cuttings and rhizomes and whole plants are discussed. Reference is made to experimental plantings set out 3 by 3 feet. The calculated yield of fibre at 2½ per cent. green weight was about 1,600 pounds per acre, which it was thought could be obtained every six months.

Dodge (6) in 1893 and 1897 reported on the propagation of sansevieria and its potentiality as a fibre crop in Florida. He noted the escape to the wild and the ease with which the flat leaved species could be propagated by leaf cuttings. *Sansevieria thyrsiflora* Thunb. (*S. guineensis* Willd.) is reported to have about 2 per cent. fibre. Preliminary trials indicated that a good crop of leaves could be harvested every year after the stand was established.

Some of the first attempts to prepare sansevieria fibre from plants cut in the wild in the Voi and Tanniland district of British East Africa are discussed by Pope (11) in 1909. The fibre is said to have been well received in the American markets for cordage because it gave about 25 per cent. more feet per pound than manila hemp but was discriminated against in the European markets because it was poorly cleaned. As discussed by Wigglesworth (15) in 1931, these ventures were later abandoned because of the lack of demand for the fibre and the necessity of going farther and farther into the bush to obtain the wild plants.

The cultivation of sansevieria in Yucatan, Mexico is discussed by de Mola (5) in 1929 and by Toro (14) in 1942. They noted the method of propagation by leaf cuttings and rhizomes and the general characteristics of the fibre species. A similar discussion on the cultivation of sansevieria in Cuba is reported by the Ministry of Agriculture (4) in 1934.

The culture of sansevieria in the British Empire is discussed briefly by Goulding (8) in 1937. Greenway (9) in 1941, and Beckley (1) in 1943 discussed the fibre characteristics of wild species in British East Africa. They reported that the commercial exploitation of the wild fibre plants failed because the

wild growth always contains some unsuitable species, and the plants cut in the wild do not recover well. In 1945 Crane and Alonzo (3) reported a yield of about 2,500 pounds of dry fibre per acre from 7 to 8 year old stands in Cuba. They found that the per cent. of fibre in *Sansevieria thyrsiflora* increased with age and length of leaf.

When the literature on sansevieria is summarized, it is found that detailed information on the agronomy of this fibre crop is very limited.

Agronomic Groups of Sansevieria Species

An attempt is made in the present paper to describe the botanical characteristics of sansevieria species and their agronomic significance by dividing them into three large intergrading groups. The botanical characteristics of representative species are given in Table 1. The leaf types are shown in Figure 1 and the characteristics of the rhizomes, in Figure 2.

The species of group I are slow growing. They are indigenous to the arid regions of Africa and show various adaptations to an arid climate and soil. Because they are difficult to propagate, have a slow rate of growth, and do not recover well after cutting, they are not considered suitable for cultivation as a fibre crop.

The species of group II have a comparatively rapid growth rate. They are indigenous to Africa but show adaptation to a tropical climate where the rainfall fluctuates from periods of high torrential rain to periods of drought. Because these species show a pronounced seasonal growth habit, they are more suited to annual harvesting than other species. Under certain conditions, such a harvest programme may be feasible in South Florida.

The species of group III have an intermediate rate of growth. They are notably absent from the arid regions of Africa and are indigenous to the coastal areas and islands of the Indian Ocean, the coasts of Africa, Arabia and India. They differ from species of groups I and II by characteristics which appear to be a result of domestication of the species in a humid climate. *S. thyrsiflora*, S. *trifasciata* var. *laurentii* (de Wildm.) N. E. Br. and *S. trifasciata* Prain have a relatively high frequency of natural somatic mutants of yellow and white chimeral variations which are highly prized as ornamental plants. These chimeral variations have not been observed in the species of groups I and II. The hard fibrous margin of the leaf, a characteristic of species in group I and group II, is much reduced in *S. thyrsiflora* and wholly absent in *S. trifasciata* var. *laurentii* and *S. trifasciata*. Although this may be a natural characteristic of the species, it appears more probable to have been selected under a period of semi-cultivation of the species. The species of group III also differ from groups I and II by extended growth of the petiole. This characteristic is particularly important from an agronomic point of view because it allows the plant to persist in tall dense stands that give a high yield of fibre per acre.

The botanical characteristics which partially define these groups are summarized in Table I. The leaf types of representative species are shown in Figure 1, and characteristics of rhizomes in Figure 2.

Fig. 1.—Plants of representative species. Group I : A, *Sansevieria ehrenbergii* Schweinf.; B, *S. cylindrica Boj.* Group II : C, *S. liberica* Ger. and Labr.; D, *S. longiflora* Sims. Group III : E, *S. thyrsiflora* Thunb. Willd; F, *S. trifasciata* var. *laurentii* (de Wildem.) N. E. Br.; G, *S. trifasciata* Prain.

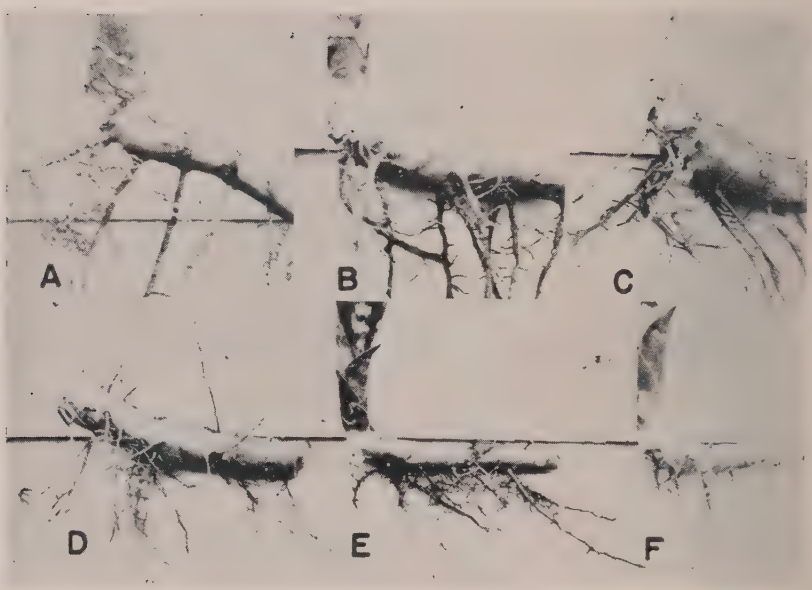


Fig. 2.—Rhizomes of representative species. Group I : A, *Sansevieria ehrenbergii* Schweinf. Group II : B, *S. liberica* Ger. and Labr.; C, *S. longiflora* Sims. Group III : D, *S. thyrsiflora* Thunb.; E, *S. trifasciata* Willd.; F. *S. trifasciata* var. *laurentii* (de Wildem.) N. E. Br.

TABLE I. *Vegetative Characteristics of Representative Species of Agronomic Groups of Sansevieria*

GROUP I		
a. Upright cylindrical leaf	Smooth round leaf ...	...*S. Cylindrica* Boj.
	Semi-round leaf on short stem	...*S. ehrenbergii* Schweinf.
b. Small to medium rhizomes few shoots		
c. long fibrous roots		
GROUP II		
a. Flat coriaceous leaf	Flat, dark green very coriaceous lightly mottled leaf, very short petiole	...*S. liberica* Ger. & Labr.
b. Large rhizomes many shoots		
c. Long fibrous roots	Flat, dark green semi-coriaceous broad, distinctly mottled leaf, short petiole	...*S. longiflora* Sims
GROUP III		
a. Long petiolar leaf	Flat, light green, lightly mottled, fibrous margined leaf, medium petiole	...*S. thyrsiflora* Thumb.
b. Small rhizomes several shoots		
c. Short fibrous roots	Flat, narrow medium green mottled, non fibrous margin, long petiole	...*S. trifasciata* var. *laurentii* (de Wild.) N. E. Br.
	Flat, narrow, dark green distinctly mottled leaf with non-fibrous margin and very long petiole ...	...*S. trifasciata* Prain.

Sansevieria cylindrica Bojer and *S. ehrenbergii* Schweinf. are considered to be representative of group I. They have a rounded cylindrical type of leaf adapted to reduced transpiration and increased water storage. The surface of the leaf is thickened and tough, adapted to withstand the high temperature, desiccation from dry winds and high light intensity of an arid climate. The more or less rigid, upright, rounded leaf, and a system of short to medium rhizomes with well developed fibrous root system are particularly characteristic of the group.

The species of group I are difficult to propagate except by division of the whole plant or clone. A 3-5 inch section of the rhizome with a 6 to 8 inch basal portion of the leaf provides a suitable planting stock. It is characteristic for the cut back leaves of the planting stock to resume growth before the proliferation of new rhizomes. New rhizomes are not usually formed until the old stock is well established. Cuttings of the leaf and segments of the rhizome are slow to root and produce few adventitious shoots.

Although many species of this group have a high fibre content, their potential acre yield of fibre is low because of their slow growth and low density of plants per unit area. Utilization of these species for fibre might prove successful in a semi-arid region, but in a humid climate such as South Florida, other species have much higher potentialities for yield. Species of group I are also unsuited to the South Florida climate because of their limited tolerance to cold.

Under group II are classed those species which have a broad, flat, leathery sclerophyllous leaf, a large thick rhizome and a moderately developed fibrous root system. *Sansevieria liberica* Ger. et Labr. and *S. longiflora* Sims are considered representative of this group. The tough, leathery leaf is adapted to withstand high temperatures with a low transpiration loss. The large thick rhizomes as shown in B and C of Figure 2, have a high survival value under droughty conditions. When placed under favourable conditions for growth, adventitious shoots are readily formed from the old rhizome. The leaf cuttings do not readily take root but do form roots and shoots more quickly than those of group I.

The species of group II have a high fibre content and a rapid rate of growth. Their potential acre yield of fibre is high but is limited by the shortness of the leaf and the low number of leaves per unit area. The value of species in group II for fibre production in South Florida is further limited by their susceptibility to cold damage. However, because of their rapid regrowth they hold some promise for annual harvesting.

Species to be considered in group III are those adapted to the tropical and sub-tropical humid climates. *Sansevieria thyrsiflora*, *S. laurentii* and *S. trifasciata* are considered in this group. They have a long, medium to narrow, thin and somewhat succulent leaf. The petiole of the leaf is longer than that found in group II and varies considerably with density of stand and conditions of growth. The rhizomes as shown in D, E and F of Figure 2, are small to medium in diameter and are shorter than those of group II. They form many more adventitious shoots than the rhizomes of group I but fewer than those of group II. The ease with which the leaf cuttings of species of this group take root is in considerable contrast to the rooting of leaf cuttings in groups I and II. Propagation by means of leaf cuttings appears practical for commercial production (10).

The species of group III show varying degrees of winter hardiness. *Sansevieria thyrsiflora* has been seriously injured by occasional near freezing temperatures during the mid-winter season. *S. laurentii* and *S. trifasciata* have not been seriously injured by these temperatures although growth has sometimes been temporarily retarded. Because near-freezing temperatures are probable during the mid-winter season of South Florida, and because several seasons are required to mature a crop of species in group III, the resistance to cold of the two latter species is of particular significance.

The length of the fibrous root system and the relative size of rhizome, petiole and leaf blade of the above species are given in Table II as the averages of ten measurements of a representative sample taken from 3 to 4 year stands.

TABLE II. *Average Measurements Botanical Characters of Sansevieria Species in Observation Plots, Boynton, Florida*

Sansevieria Species	Fibrous Roots	Rhizome		Petiole Length	Blade	
		Width	Length		Width	Length
GROUP I						
S. ehrenbergii	20	0.7	8.6	—	1.4	31.0
S. cylindrica	19	0.7	7.1	—	1.0	29.0
GROUP II						
S. liberica	17	1.1	12.7	4.9	2.8	26.0
S. longiflora	14	1.4	12.1	11.0	4.4	25.0
GROUP III						
S. thyrsiflora	7	0.7	8.5	15.0	3.3	21.2
S. trifasciata var. *laurentii* ...	8	0.6	4.5	22.7	3.5	23.3
S. trifasciata	6	0.6	6.7	33.7	2.3	23.6

The long fibrous root system of group I, the large rhizome of group II and the long petiole of group III are particularly evident. These characteristics of the groups represent difference in types of development, and are not generally affected by conditions of growth. Differences between species, on the other hand, are more a matter of degree and are likely to be affected by the adaptation of the species to a particular environment.

It may be seen from these comparisons of Table II, that there tends to be a continuous series of variation of a particular structural part when species of all groups are considered. However, the combinations of characteristics appear to be limited by natural selection within groups. For example, the long fibrous root system, the short to medium rhizome and the round leaf are found as associated characteristics or adaptations of species in group I. It is to be assumed that the best survival characteristics are probably to be found already combined in the climatic adaptations discussed. For the production of sansevieria fibre in Florida, the species of group III, adapted to a humid tropical and sub-tropical climate, might logically form the basis of selection, particularly those species which show some degree of winter hardiness. The characters for quantity and quality of fibre might be introduced from other species.

PER CENT. YIELD OF FIBRE AS RELATED TO LEAF TYPE

The mature leaves of sansevieria species differ in size, shape and type. As shown in Figure 2, *S. ehrenbergii* (group I) has an inside groove in the leaf while *S. cylindrica* is completely round. The leaf of *S. liberica* (group II) is shorter and narrower than *S. longiflora* (group II) and is more coriaceous. *S. thyrsiflora*, *S. laurentii* and *S. trifasciata* (group III) differ largely by width of blade and length of petiole.

The relationship of leaf size, shape and type to per cent. yield of fibre was studied by mechanically cleaning and water retting the base, middle and tip sections of the leaf. Mechanical cleaning was used to determine the practical yield of fibre, excluding tow. Water retting was used to obtain an

estimate of total fibre. Retted fibre yields are generally higher than decorticated yields because of mechanical loss in decortication. In some cases however, retted yields may be lower than decorticated yields because the decorticated fibre may contain extraneous materials.

Five leaf samples from 3- to 4- year stands at Boynton, Florida were taken for fibre determination. The results of these determinations are given in Table III. Due to the unreplicated nature of the observation plots, no attempt is made to determine significant differences, but because of the uniformity of the soil, and the similarity of the samples, the data are thought to be quite reliable.

The per cent. mechanically cleaned fibre plotted against the mid-section height of the leaf is illustrated in Graph 1. The round leaf species of group I are found to differ from the other groups by an increase in per cent fibre from base to tip. The low per cent fibre of the base of the leaf is due to the large amount of fleshy pulp which functions in water storage. The actual amount of fibre decreases from base to tip. The species of group II have the highest content of fibre and the highest rate of decrease per unit of height. The high content of fibre appears to be related to the coriaceous structure of the leaf and the rapid decrease in per cent. of fibre per unit of height, to the number of short fibres which terminate at the mid-section of a broad leaf. Thus, *S. liberica*, which has the most coriaceous leaf, has the highest content of fibre. *S. longiflora*, which has the broadest leaf, has the highest rate of decrease of fibre per unit of length.

TABLE III. *Percent Yield of Fiber as Related to the Leaf Type and Species of Sansevieria*

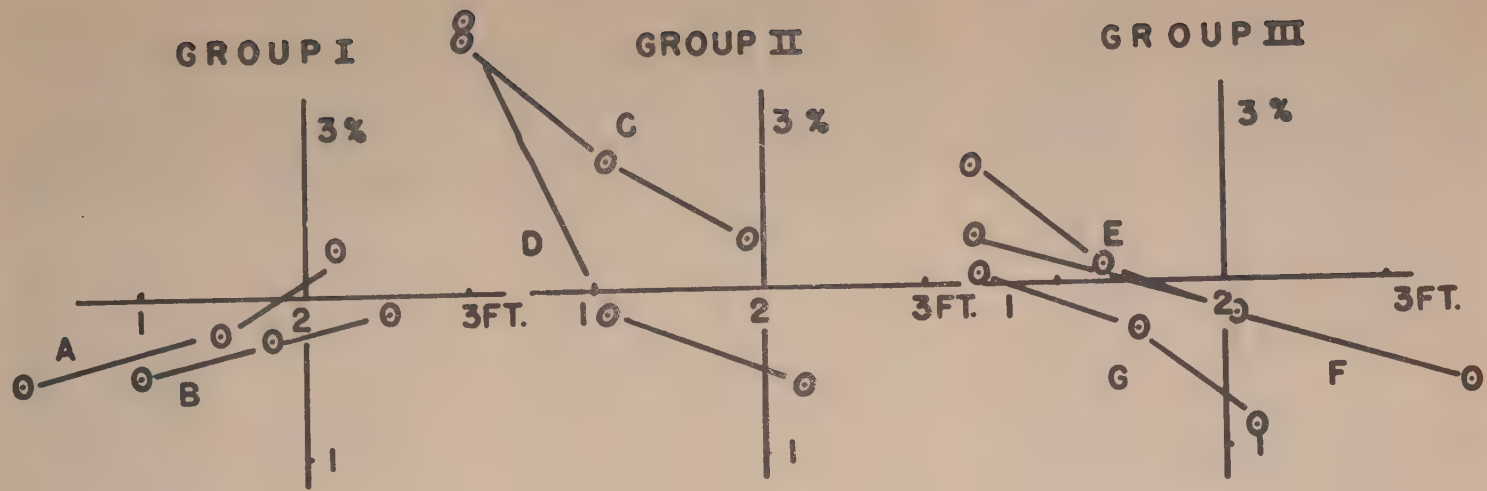
Sansevieria Species and Type	y% x ht.	Mechanically Cleaned				Water Retted			
		Base	Middle	Tip	byx	Base	Middle	Tip	byx
Group I									
S. ehrenbergii ...	y %	1.44	1.85	2.24	0.41	1.57	1.63	1.96	.27
Round leaf ...	x ht.	0.30	1.42	2.18	—	.58	1.00	2.08	—
S. cylindrica ...	y %	1.53	1.78	1.82	0.19	1.31	1.73	2.23	0.54
Round leaf ...	x ht.	1.00	1.77	2.56	—	.38	1.29	2.08	—
Group II									
S. liberica ...	y %	3.54	2.75	2.33	—0.69	3.07	2.88	2.49	—0.41
Coriaceous leaf ...	x ht.	0.17	1.08	1.92	—	0.77	1.48	2.20	—
S. longiflora ...	y %	3.64	1.84	1.42	—1.06	3.63	1.93	1.21	—0.99
Coriaceous leaf ...	x ht.	0.17	1.17	2.25	—	0.48	1.77	2.95	—
Group III									
S. thyrsiflora ...	y %	2.76	2.11	1.74	—0.60	2.95	2.12	1.54	—0.67
Intermediate leaf ...	x ht.	0.30	1.28	2.01	—	0.63	1.80	2.73	—
S. trifasciata var. *laurentii* ...	y%	2.09	1.72	1.17	—0.46	1.72	1.19	0.88	—0.34
Petiolar leaf ...	x ht.	0.29	1.45	2.20	—	0.95	2.50	3.39	—
S. trifasciata ...	y %	2.35	1.80	1.44	—0.27	2.45	1.80	1.38	—0.35
Petiolar leaf ...	x ht.	0.25	2.17	3.58	—	1.39	3.42	4.39	—

1—Average values of 5-leaf samples of approximately 3 year growth, near Boynton, Florida.

y%—Percent dry fiber per green weight of leaf section.

x ht.—Height in feet from base of plant to middle of section.

byx—Regression of percent dry fiber on height in feet from base to mid-section of leaf.



GRAPH 1. Per cent yield of mechanically cleaned fibre of sansevieria species from base, middle and tip sections of the leaf, plotted against the base-to-midsection height. A, *Sansevieria ehrenbergii;* B, *S. cylindrica;* C, *S. liberica;* D, *S. longiflora;* E, *S. thyrsiflora;* F. *S. trifasciata;* G, *S. trifasciata* var. *laurentii.*

The species of group III have a relatively low per cent of fibre and an intermediate rate of decrease of fibre per unit of height. The low per cent. of fibre is partly due to the greater height of these species. Since there is a decrease in fibre per unit of height, common to all species, short species tend to have a higher average fibre content than tall species.

The low rate of decrease in fibre per unit of length is related to the petiolar type of leaf of group III. In this type of leaf most of the fibres are found to extend the full length of the leaf.

When the per cent. yield of fibre of all species are taken as a whole, it is found that part of the differences in fibre content are explained by the size, shape and type of leaf. Other differences are known to be related to the age and particular conditions of growth. Varietal differences for the inheritance of fibre content are probably to be found within species.

Acre Yield Characteristics of Sansevieria Species

The potential acre yield of a fibre crop such as sansevieria depends upon the height of growth, the number of leaves per unit of area per unit of time, and the average percent fibre. The yield characteristics of sansevieria species from observation plots near Boynton, Florida on Leon fine sand under moderate fertilization, are summarized in Table IV. The yield of green weight is based upon leaves over 20 inches in length, cut by hand at the surface of the ground. These yields are probably higher than would be obtained by mechanical harvest because of the loss in the stubble. The yields of group I are calculated from plots of 10 square feet or less. The yields of group II and III are calculated from plots of 25 square feet or more. The plot yields of *S. thyrsiflora* have been found to agree well with yields under average field conditions but may be somewhat increased by high nitrogen fertilization. The yields of other species should be considered as preliminary observations.

Of the various aspects of growth which determine fibre yield, the density of stand or number of leaves per unit area appears to be the most important factor. The species of group III, by elongation of the petiole are capable of growing in stands many times as dense as those of groups I and II. Even though the percent of fibre per green weight is lower, the potential yield of fibre per acre of species in group III is much greater.

From the annual growth rate and general observation of stand it is found that the species differ greatly in the length of time required to produce a mature stand. Assuming plants are planted one plant per square foot, it is estimated that 5 to 10 years are required for maturity of stand of group I, 2 to 3 years for group II and 5 to 5 years for group III. These generalizations are related to the type of growth found in the different groups, and are substantiated in the prelimary yield data of Table IV.

TABLE IV. *Fiber Yield Characteristics of Sansevieria Fiber of Observation Plots as grown at Boynton, Florida*

Sansevieria Species and Age of Growth	Average Plant Height in Inches	Leaves Harvested Per Sq. Ft (over 20 inches)	Computed Acre Yield Tons Green Wt.	Average Percent Decorticated Dry Fiber	Computed Acre Yields Pounds Dry Fiber	Annual Acre Yield, Pounds Dry Fibre
GROUP I						
S. ehrenbergii						
2 Year ...	31	3	39.42	1.62	1,277	638
S. cylindrica						
2 Year ...	29	6	34.62	1.32	914	457
GROUP II						
S. liberica						
2 Year ...	30	11	63.46	2.36	2,945	1,497
S. longiflora						
2 Year ...	30	13	86.15	1.79	3,084	1,542
3 Year ...	35	25	134.16	2.07	5,554	1,851
GROUP III						
S. thyrsiflora						
2 Year ...	32	17	67.33	1.56	2,101	1,050
3 Year ...	31	20	100.41	1.56	3,132	1,044
S. trifasciata var. *laurentii*						
2 Year ...	36	23	82.05	0.96	1,591	796
3 Year ...	41	34	158.80	1.25	3,970	1,323
S. trifasciata						
2 Year ...	43	29	116.80	1.56	3,615	1,806
3 Year ...	50	34	259.28	1.48	7,475	2,491

The species of group I have a slow growth of leaves. The number of leaves per plant and the number of shoots per rhizome are few. Thus, the stand is slow to mature. The leaves of group II grow rapidly and the number of leaves per plant and the number of shoots per rhizome are many. The surface area of ground is therefore rapidly covered with tufts of short leaves and the maturity of stand is quickly reached. The species of group III grow fairly rapidly but their growth is of a more perennial nature. The leaves continue growth in length for several years. The number of leaves per plant and the number of plants per unit of area increase until the stand becomes very dense. Such a stand matures more rapidly than that of group I but less rapidly than that of group II. The limited growth of *S. thyrsiflora* as shown by the average annual yield is thought to be due to frost damage. This forces maturity of the plant and the growth in length of leaf and the growth of new leaves are very much limited. In areas of wild growth protected from frost damage, taller and more dense stands are found, apparently, because growth continues to a natural maturity of stand.

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CITRUS EXPERIMENTS AT THE ST. AUGUSTINE EXPERIMENT STATION, TRINIDAD, B.W.I.

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Author's Summary

The results of a series of experiments on citrus laid down in 1932 at the St. Augustine Experiment Station, Trinidad, B.W.I. are given and conclusions drawn.

The best stock for Marsh grapefruit has proved to be the Sour Orange. No other stock has outyielded it, it shows the greatest resistance to gummosis and the quality of the fruit on it has been better than on the other stocks tried.

Of the three oranges tested Washington Navel, Valencia and Pineapple, only the Valencia has proved suitable for the export market and again the Sour Orange has proved the best rootstock.

On Sour Orange stocks budding for both Marsh grapefruit and Valencia oranges should be done at not less than 15 inches from the ground.

On the soils in question, with a basic dressing of 150 lb. pen manure and one-half pound superphosphate per annum, increased yields are obtained with 3 lb. and 4½ lb. of ammonium sulphate. No increase is found with potash alone or in combination with nitrogen.

An increase in gummosis has been found associated with nitrogenous fertilising.

The shortcomings of the statistical layouts are discussed.

Introduction

In 1932, a series of experiments was laid down at the St. Augustine Experiment Station of the Department of Agriculture to investigate various aspects of grapefruit and orange cultivation in Trinidad. With declining cocoa yields, these fruit and in particular grapefruit were being considered as a new export crop and plantings were being made by estates with little or no local experimental evidence as to optimum cultural methods. Commercial plantings were made following the general lines adopted in other countries and these experiments were started to confirm or amend these practices for local conditions.

The layout of the experiments is given in detail by Williams (1) and Progress Reports have been made by Williams and Gregory (2), Gregory (3) and Bain (4). After the 1947–48 crop, 16 years from planting, the experiments had given all the information that they were likely to give and they

were discontinued. Most of the information is now well known and has passed into general practice but it is necessary to put on record the full results of each experiment. To obviate frequent reference to the earlier papers a brief summary will be given of each experiment. but for full particulars the original papers must be consulted.

Soil and Rainfall

The experimental area is situated on a deep sandy loam derived from river alluvium brought down from the Northern Range quartz schists. Neutral to slightly acidic, it is fairly well drained and in the early days of citrus culture in Trinidad this soil type was considered ideal for the growth of the crop. Soils of this type are, however, rather limited in Trinidad and commercial plantings have been extended to the heavy clays of other parts of the island. It does not follow therefore that results at St. Augustine will apply to other soil types particularly with regard to manurial and fertiliser practices.

The annual rainfall averages 67 inches of which 55 inches fall in the wet season from July to December and the remaining 12 inches in the dry season of January to June. The crop year is reckoned from July to June.

Experiment I—Stocks for Marsh Grapefruit

This experiment was designed to test the relative merits of Sour Orange, Sweet Seville, Rough Lemon and Wild Grapefruit as stocks for Marsh grapefruit and to test four parent trees in each stock group.

The layout was to have comprised a 4 × 4 Latin Square of the 4 stocks with plots of 12 trees. Each plot contains the 4 parent trees of that stock replicated three times, the four parent trees being arranged at random in one row. However, Williams (1) states "Land economy necessitates the whole experiment being divided in half and the halves placed side by side." In practice the halves were placed end to end thus defeating the purpose of a Latin Square and making statistical analysis by this technique impossible.

The experiment has however been running so long that in spite of the short-comings of the layout, certain conclusions can still be drawn. Records have been taken for yield, girth and incidence of gummosis and these will now be examined.

Yields : Individual tree recording was begun as soon as the trees came into bearing, and a mass of data is available. The average annual yield on each stock is given in Appendix I. Previous to 1944 all records are for numbers of fruit, but from that year recording was changed to weight of fruit as this constitutes the normal commercial measure of yield. Unfortunately no record of numbers in succeeding years was taken so that no conversion factor is available and the periods must be dealt with independently.

In the early years it may be noted that the Rough Lemon, though usually considered a forcing stock, is only very little ahead of the Sour Orange both as regards earliness in coming into bearing or early yields.

A summary of the yields on the four stocks is :—

Stock		*Average No. of fruit per annum* 1934–44	*Average weight (lb.) of fruit per annum* 1944–48
Sour Orange	...	243	426
Sweet Seville	...	204	433
Rough Lemon	...	213	380
Wild Grapefruit	...	202	305

The analysis of variance carried out by Bain (3) on the 1942–44 yields put the Sour Orange significantly ahead of all other stocks. When the weights of fruit for the last four years are considered however, the Sweet Seville is now proving just as high yielding a stock and it is unnecessary to carry out an analysis of variance to determine the relative relations of the Sour Orange to the Rough Lemon and Wild Grapefruit stocks. It is sufficient to say that as far as yields go, no stock is any better than the Sour Orange and other reasons confirm it as the most suitable rootstock for Marsh grapefruit in Trinidad.

Girth Measurements : Measurements were made on both stock and scion at 16 and 36 cm from ground level, i.e., 10 cm approximately above and below the bud union in January and July each year until they were discontinued in July, 1945. These figures disclose nothing of particular interest but the actual girths at January, 1945 were :—

		Girth in cm., mean of 48 trees.		*Stock minus Scion*
Stock		*Stock*	*Scion*	
Sour Orange	...	78.0	80.2	—2.2
Sweet Seville	...	84.6	82.4	+ 2.2
Rough Lemon	...	90.8	74.4	+16.4
Wild Grapefruit	...	83.9	77.5	+ 6.4

The trees on Sour Orange roots had the smallest stock girth and with both this stock and Sweet Seville, high yields appar connected with the smoothness of the bud union, i.e., the difference in girth of stock and scion rather than with the actual stock or scion girth, though this cannot be demonstrated statistically.

Gummosis : The incidence of gummosis in May, 1947 was :—

Stock		*Trees infected on Stock*	*Trees infected on Scion*
Sour Orange	...	5 [10]	8
Sweet Seville		6 [12]	9
Rough Lemon	...	7 [14]	14
Wild Grapefruit	...	25 [50]	15

Figures in brackets indicate percentages.

These figures are about double those given by Bain in 1943 and are high by commercial standards. During the war years the trees did not receive the usual standard of maintenance and this must be partly to blame. Evidence has been accumulated however, to show that gummosis incidence

in Trinidad is largely affected by soil type and fertiliser practice, a point to be discussed later. By careful inspection of trees and early removal of diseased tissues gummosis on Sour Orange is seldom serious in a well kept commercial orchard in Trinidad.

Stock Parent Trees : As the Sour Orange is the only commercial stock, only the four parent trees of this stock will be considered. Taking yields from 1937 the year in which all trees on this stock first came into bearing, comparative totals are :—

Sour Orange Stocks	*Average No. of fruit per annum* 1937–44	*Average weight of fruit per annum* 1944–48
(*a*) Barnado—2 ...	314 [100]	414 [100]
(*b*) River—2 ...	322 [106]	402 [97]
(*c*) Government Farm—1 ...	347 [110]	459 [119]
(*d*) St. Clair—2 ...	359 [114]	432 [104]

The figures in brackets give the yields as a percentage of (*a*).

The analysis of variance disclosed no significant difference between stocks on the 1944–48 averaged yields. On carrying the analysis a stage further and using annual yields, the differences between seasons proved significant at P=.05 and the interaction of season and block was also significant. The variety X season interaction was non significant. The standard deviation even for the four year totals proved to be 24 per cent. of the mean suggesting that single tree plots were inadequate for this comparison.

Experiment VII—Stocks for Oranges

Three separate 4 × 4 Latin Squares were laid down to test Washington Navel, Valencia and Pineapple Oranges respectively on the same stocks as those used in the grapefruit trial. In each plot there were 4 trees, one of each of the parent trees arranged at random. Each trial will be dealt with separately.

Washington Navel Orange : The yields in this trial summarized are :—

Stock	*Average No. of fruit per tree per year* 1942–44	*Average weight (lb.) of fruit per tree per year* 1944–48
Sour Orange ...	210	190
Sweet Seville ...	169	161
Rough Lemon ...	162	146
Wild Grapefruit ...	101	129

Bain for the 1942–44 figures determined a significant difference only between the Sour Orange and Wild Grapefruit stocks, the significant difference for P=.01 being 100 fruit. Consequently the analysis for the 1944–48 yields has been considered unnecessary, and it is sufficient to state that no stock is better than the Sour Orange for Washington Navels. Furthermore, the Washington Navel has proved unsatisfactory for commercial plantings under

Trinidad conditions for several reasons. Yields are low as compared with the Valencia, quality and flavour are poor and the trees will not hold their fruit as long as the Valencia. The results of this trial are therefore of little practical interest.

Valencia Orange : This orange constitutes the bulk of the commercial plantings in Trinidad. Yield, quality and flavour on Sour Orange stock are all good and moreover the fruit will hang on the trees until the very end of the dry season, a time when the best prices can be secured on the export market. A summary of yields is :—

Stock		*Average No. of fruit per tree per year* 1942–44	*Average weight (lb.) of fruit per tree per year* 1944–48
Sour Orange	...	400	277
Sweet Seville	...	458	281
Rough Lemon	...	384	291
Wild Grapefruit	...	310	219

For the 1942–44 figures, Bain found that the differences even though they are in the region of 30 per cent. were not significant. Evidently the 1944–48 figures based on weights will be unlikely to differ significantly and the trial may be said to show only that none of the stocks is any better than the Sour Orange as far as yields go. The quality of the fruit on this stock is moreover so much better than it is on the other three rootstocks that this feature alone would confirm the Sour Orange as the best of the four rootstocks.

Girth measurements : A mass of data is available but nothing of particular interest is apparent. For record purposes the average girths at January, 1945 on the four rootstocks are given in Appendix II.

The variability in these measurements is high but the trends in each trial are similar, the Sour Orange giving the smoothest bud union and the Rough Lemon being the most overgrown. There is no apparent relation between any of these girth measurements and yields.

Pineapple Orange : A summary of the yields in this trial follows :—

		Average No. of fruit per tree per year 1942–44	*Average weight (lb.) of fruit per tree per year* 1944–48
Sour Orange	...	416	250
Sweet Seville	...	483	241
Rough Lemon	...	343	203
Wild Grapefruit	...	263	158

Again Bain found that the differences in yields for the 1942–44 period were not significant and in consequence the 1944–48 yields have not been analysed. The yields on the four stocks run a little lower than do the Valencia on the same stocks but there is no way of determining whether the differences are significant. The Pineapple Orange, though of good flavour and quality is not of sufficient commercial importance to merit any further attention.

With regard to the stock parent trees variability is again too high to differentiate between them.

Experiment III—Height of Bud Insertion for Grapefruit

Sour Orange seedlings from tree River 2 were budded at heights of 2, 5, 10, 15, 20 and 25 inches from ground level respectively and planted out in 8 Randomised Blocks, each block containing a single tree of each treatment. The object lay in determining the relation between height of budding and gummosis incidence, and in addition records were taken of yields and girth.

Gummosis : The incidence of gummosis was checked in May, 1947 and records made for both stock and scion the degree of infection being marked as mild—1, medium—2, severe—3.

Incidence of Gummosis

	No. of trees affected		*(Average degree of infection)*	
	Stock	*Scion*	*Stock*	*Scion*
2 inches ...	5	5	2.4	2.4
5 do. ...	6	4	1.8	2.0
10 do. ...	4	3	1.5	2.9
15 do. ...	3	2	2.3	3.0
20 do. ...	1	0	1.0	—
25 do. ...	0	1	—	3.0

These figures confirm that to avoid gummosis, budding should be done as high as possible and at not less than 15 inches. Even at this height the incidence of gummosis in this trial is very high but the numbers of trees dealt with are small.

Yields : It is of some interest to determine whether height of budding makes any difference to the yield of the tree and the following table is a summary of the records :—

Height of budding (ins.)	*Average No. of fruit per tree per annum* 1934–44	*Average weight (lb.) of fruit per tree per annum* 1944–48
2	305	417
5	282	409
10	276	469
15	272	476
20	287	435
25	275	468

The analysis of variance discloses no significance between the 1944–48 yields at P=.05. The standard deviation as a percentage of the mean works out at just under 20 per cent.

Girth Measurements : Measurements of the girths in cm. above and below the bud union at January, 1945 are :—

	Stock	*Scion*	*Stock minus Scion*
2 ...	97.5	88.5	9.0
5 ...	88.6	81.5	7.1
10 ...	82.9	82.1	0.8
15 ...	76.1	79.2	—3.1
20 ...	73.9	76.7	—2.8
25 ...	72.3	77.4	—5.1

Girth of stock and scion is greater at the 2 inch height of budding decreasing generally to the 25 inch height, a feature to be expected from the natural taper of the tree. Of interest, however, is the difference between the stock and scion at the different heights. Up to 10 inches the stock has overgrown the scion and above this height the scion has overgrown the stock. Comparing these differences with the yields there seemed an indication that higher yields were associated with the smoothness of the union and a correlation of 0.72 was obtained, but this proved non-significant.

Experiment VIII—Height of Bud Insertion for Oranges

This experiment is similar to the last except that the scion used was the Jaffa Orange. There has been very little gummosis in this trial as compared with the grapefruit trial. In May, 1947 only two trees were found infected, both very lightly. Both were budded at 2 inches from the ground and one was infected on the stock and the other on the scion.

Yields :

Height of budding (ins.)	*Average No. of fruit per annum* 1934–45	*Average weight (lb.) of fruit per annum* 1944–48
2	129	166
5	110	183
10	107	192
15	103	219
20	103	207
25	95	133

There seems to be an indication that over the last 4 years, yields increase as the height of budding goes up but the 25 inches budding figures do not agree with this. Variability is again so high that the Analysis of Variance disclosed no differences as significant.

Girths :

	Stock	*Scion*	*Stock minus Scion*
2	72.1	61.4	10.7
5	72.5	60.8	11.7
10	63.1	57.1	6.0
15	63.1	58.7	4.4
20	62.7	57.1	5.6
25	57.5	53.8	3.7

The trend in girths is similar, though lower, to the grapefruit trial. With the orange scion, however, the Sour Orange stock always overgrows the scion but the disparity decreases with increasing height of budding. Again, apart from the 25 inches budding, high yields appear associated with smoothness of union but no explanation can be offered for the apparent anomaly at 25 inches. For practical purposes, however, to bud at not less than 15 inches would appear satisfactory.

Experiment VI—Manurial Trial

This experiment was laid down to compare the effect of various treatments with artificial fertilisers and organic manures on quality and yield of Marsh Grapefruit on 3 types of stock. Details of the treatments and layout are given by Williams (1) and a progress report was made by Gregory (3).

It is not proposed to recapitulate the early general conclusions, for the fertiliser treatments were so unbalanced that the trees developed severe mottle leaf, probably due to minor element deficiencies and a high percentage of gummosis. Bain (4) therefore modified the treatments discarding trees on Rough Lemon and Wild Grapefruit and converting the experiment into a 4 × 4 Latin Square with 12 trees on Sour Orange in each plot. And in order to even up the plots and try to eliminate differences due to previous treatments, during 1938 and 1939, pen manure was applied to all plots except those receiving pen manure previously.

In 1940 four new treatments were started on the modified layout.

All trees received an annual basic treatment of 100 lb. pen manure plus ½ lb. superphosphate, a dressing which was considered the minimum treatment necessary to keep citrus at a subsistence level under the soil conditions existing in the plots.

The annual treatments were :—

I. Control
II. Ammonium sulphate at 4½ lb. per tree
III. Sulphate of Potash at 4½ lb. per tree
IV. Ammonium sulphate at 3 lb. plus sulphate of potash at 3 lb. per tree.

The yields per tree are given in Appendix III. From 1938–40, all trees received the same application of pen manure, from 1940–44, the trees were receiving the applications given above and yields were recorded in number of fruit and from 1944–48, the recording was changed to weight of fruit.

Also given is a table of yields expressed as a percentage of treatment I. Bain considered that the 1942–44 average yields were sufficient to give tentative results as the trees had then settled down to the new treatments.

	Average No. of fruit per annum 1942–44	*Difference from Control*	*Average weight of fruit per annum* 1944–48	*Difference from Control*
I Control	278	—	281	—
II N	471	193	496	215
III K	347	69	307	26
IV N + K ...	476	198	442	161

Bain found that a difference of 72 fruit was significant at P=.01 for the 1942–44 average. The 1944–48 average shows a very similar range and even without resource to statistical significance, Bain's conclusions that nitrogen alone and in combination with potash has given rise to significantly increased

yields, that potash alone does not increase yields and that potash in combination with nitrogen does not increase the yield with nitrogen, appear valid. There is some reason to believe from the 1944–48 figures that yield increases are in direct proportion to nitrogen, for Treatment II with 50 per cent. more ammonium sulphate than IV is giving 30 per cent. more fruit. A statistical approach involves such difficulties as to be not worth attempting. To co-variance treatment yields with the 1938–40 yields is not valid without knowledge of the residual effects of previous treatments and the trees in IV may have been so far ahead of the other 3 treatments that future treatments will always be biased.

One further practical consideration may be tentatively drawn. The fall in yields from the good years 1944–46 to the poor years 1946–48 is much less marked when the trees have received nitrogen than when they have not.

Gummosis : As stated earlier, gummosis incidence has been high in this trial particularly on Rough Lemon and Wild Grapefruit. Even on Sour Orange, there has been far more than is desirable in a commercial orchard; figures in May, 1947 being :—

		No. of trees infected on		*Average degree of infection*	
		Stock	*Scion*	*Stock*	*Scion*
I	...	4	7	1.2	1.7
II	...	10	10	1.4	2.2
III	...	6	7	1.3	1.6
IV	...	3	11	1.7	2.0

There seems to be an indication from these figures that gummosis is associated with high dosage of artificial nitrogen, ammonium sulphate at $4\frac{1}{2}$ lb. per tree resulting in more than $2\frac{1}{2}$ times the infection found on the control.

A possible explanation lies in the time of application of the fertiliser which is applied in May just before the rains start and results in very vigorous growth with the early rains. This growth may be so vigorous as to result in bark splitting thus making conditions far easier for the ingress of the causal organism of gummosis. This is more apparent from the examination of the trees than from actual girth measurements which follow.

		Stock	*Scion*	*Stock minus Scion*
I	...	64.2	72.6	—8.2
II	...	67.5	76.1	—8.5
III	...	66.4	75.2	—8.8
IV	...	67.9	77.3	—9.4

Treatments II and IV have led to the larger girths, but treatment II shows the highest gummosis. This relationship between high nitrogen and gummosis is also shown in the following experiment.

Experiment IX—Demonstration Block

A block of 56 trees of Marsh Grapefruit budded on Sour Orange was divided in half. Plot A was to receive no fertiliser or manure and the minimum of cultivation, cutlassing being done only twice a year to keep down weeds and grass. The other plot received what was considered the optimum estate treatment, good cultivation and the application of pen manure and fertiliser at the rates per tree per annum of—

3 lb. Ammonium sulphate
2½ ,, Sulphate of Potash
½ ,, Superphosphate
150 ,, Pen manure

The effect of the fertiliser is clearly seen in the comparative yields for which figures are given for the period 1944–48.

Yield per tree per annum (lb.) mean of 28 trees.

	Plot A	*Plot B*
1944–45	195	576
45–46	305	656
46–47	137	582
47–48 ...	133	363

The fertilised plot is giving three times the weight of fruit that the unfertilised plot is giving but an unexpected feature is the incidence of gummosis in the plots.

	No. of trees affected on	
	Stock	*Scion*
Plot A	—	2
Plot B	13	19

It seems clear that a heavy dose of fertiliser at the end of the dry season produces a condition in the tree making it more susceptible to gummosis than when the tree has not been fertilised at all. The girth measurements in this trial are :—

	Stock	*Scion*	*Stock minus Scion*
A ...	68.4	72.6	—4.2
B ...	76.2	82.4	—6.2
B—A	7.8	9.8	

The conclusion seems justified that applying a large dressing of fertiliser at the end of the dry season is not altogether a desirable practice and that it may be better to apply fertilisers during a break in the rains, say, July, and in the short dry season of September–October. This can only be determined by further experimental work.

Discussion : One of the striking features of these experiments is the disappointing amount of precise information that has been derived from experiments over which a great deal of care, attention and money were spent and which have been in progress for 16 years. Any experiment with tree crops presents considerable practical difficulties : the tree occupies a considerable area of land, it takes several years to come into bearing and several more years must elapse before the yields can be compared. These difficulties

were realised when the experiments were devised and the layouts were carefully planned. It is clear from the results however that the layouts were not adequate to demonstrate that such differences as have occurred are statistically significant. Even with the means of 4 years' yields, at 12–16 years, when the trees would be expected to have settled down, the coefficients of variation have proved very high.

It is not proposed to discuss possible statistical methods of dealing with the problem but merely to stress the fact that the design and layout of trials for tropical tree crops needs considerable further study. Pearce (5) discussing a very similar problem for apple trees concludes that in a trial where the treatments are applied from the time of planting as in the rootstock and height of budding experiments, no useful means of adjusting yield figures with girth measurements can be found.

In general, increasing the number of trees per plot reduces the co-efficient of variability but there are practical difficulties involved and the present tendency seems to favour a return to single tree plots with adequate replication and careful selection of planting material for uniformity. The height of budding trials have however shown that single tree plots with 8 replications are inadequate in reducing the coefficient of variability below 20 per cent.

A great deal of further knowledge seems required on the nature and extent of so called uncontrolled variation. In citrus, the annual variation in yield of a single tree is complex. Rainfall is important but individual trees seem to follow no easily determined pattern. Marked biennial bearing does not seem to occur but a tree may give good crops for two or three years followed by a poor crop and different trees even from the same scions exhibit different patterns.

The standard layouts cope with general fertility gradients but it may well be that in the wet tropics these are overshadowed by local differences in physical structure of the soil, particularly those factors affecting drainage. It is often possible in the field to spot localised sites where water logging seems prevalent even though these trials all carried surface drains. Cultural treatments should clearly be such as to give optimum conditions for growth so that no factor other than the experimental treatments is limiting.

The individual trials require little further comment. The Sour Orange has been confirmed as the best of the four stocks for Marsh Grapefruit and Valencia oranges under the conditions of the trial. At present citrus in Trinidad is apparently free from the numerous virus diseases of other countries but should tristeza appear alternative stocks would need to be considered. The budding of citrus at not less than 15 inches from ground level is now accepted practice but the association on this soil of gummosis susceptibility with heavy nitrogenous fertilisation in the dry season needs consideration. On the heavy clays in other parts of the island where the bulk of the later planting of citrus has been done, this association seems less marked even though it has become a standard practice to apply 3–6 lb. of ammonia sulphate per tree at the end of the dry season.

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APPENDIX I

Experiment I

Average yield of fruit per tree, mean of 48 trees.

(*a*) *Number of fruit*

Figures in brackets indicate number of trees in bearing.

	Sour Orange	Sweet Seville	Rough Lemon	Wild Grapefruit
1934–35 ...	16 [45]	13 [27]	26 [44]	11 [31]
35–36 ...	12 [40]	7 [39]	13 [42]	6 [28]
36–37 ...	43 [45]	18 [38]	59 [47]	29 [45]
37–38 ...	193 [48]	136 [48]	199 [48]	151 [48]
38–39 ...	58	70	116	90
39–40 ...	383	301	369	355
40–41 ...	253	271	374	345
41–42 ...	505	419	396	408
42–43 ...	254	176	179	311
43–44 ...	719	641	419	336
Total fruit ...	116,712	98,014	102,120	96,958
Average fruit per tree per annum ...	243	204	213	202

(*b*) *Weight of fruit in lb.*

1944–45 ...	425	445	407	290
45–46 ...	492	470	397	324
46–47 ...	374	361	360	328
47–48 ...	414	457	355	279
Total weight of fruit	1,705	1,733	1,519	1,221
Average weight per tree per annum ...	426	433	380	305

APPENDIX II

GIRTHS, Means of 16 trees (cm.)

	Stock	Scion	Stock minus Scion
Valencia on			
Sour Orange	60.5	57.3	+ 3.2
Sweet Seville	65.6	58.2	+ 7.4
Rough Lemon	76.5	61.2	+ 15.3
Wild Grapefruit	64.8	55.1	+ 9.7
Washington Navel on			
Sour Orange	67.2	61.7	+ 4.5
Sweet Seville	68.7	60.8	+ 7.9
Rough Lemon	81.6	64.2	+ 17.4
Wild Grapefruit	75.1	64.9	+ 10.2
Pineapple on			
Sour Orange	56.2	54.0	+ 2.2
Sweet Seville	59.8	54.0	+ 5.8
Rough Lemon	67.2	57.7	+ 9.5
Wild Grapefruit	68.3	54.8	+ 13.5

APPENDIX III

Average yield per tree, mean of 48 trees

Number of fruit

	I	II	III	IV
1938–39	61	97	137	246
39–40	241	299	293	419
40–41	171	232	244	287
41–42	253	499	329	551
42–43	116	405	184	471
43–44	439	539	509	477
Weight of fruit in lb.				
1944–45	413	570	414	512
45–46	409	647	417	556
46–47	148	363	215	359
47–48	156	403	181	340

Tree Yields expressed as a percentage of Treatment I

	I	II	III	IV
1938–39	100	159	224	403
39–40	100	124	121	173
40–41	100	135	143	168
41–42	100	197	130	218
42–43	100	341	158	407
43–44	100	122	115	108
44–45	100	138	100	123
45–46	100	158	101	135
46–47	100	245	145	242
47–48	100	258	116	155

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THE GARDEN HOSE—U-TUBE LEVEL

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The use of make shift instruments for the performance of any function to which they may be adapted is very often a necessity in the absence of their standard counterparts. Generally also the care and attention which sensitive standard instruments require in operation do not justify their being entrusted in the hands of inexperienced people. Whenever, therefore, the work in hand calls for only moderate accuracy, improvised instruments of rugged construction and capable of simple adjustment when necessary are, economically, the most feasible.

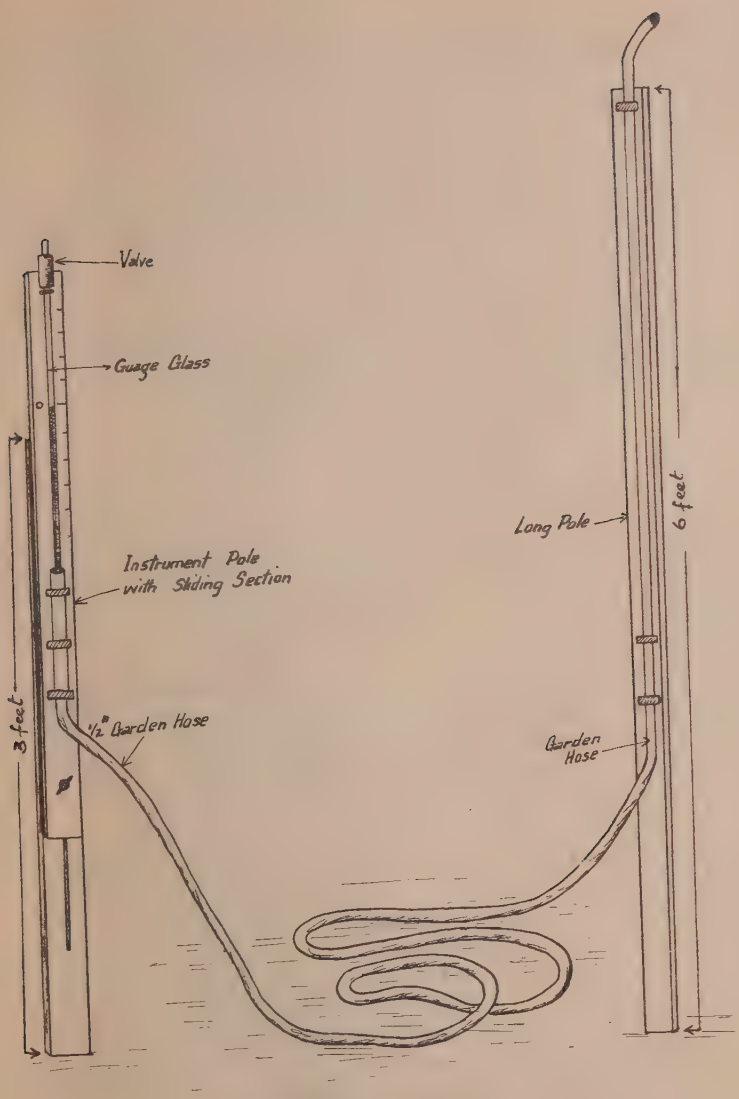
In the laying out or checking of contours, drainage grade lines, terraces, and other simple jobs in differential levelling, a variety of such improvisations are possible and in use. One of these is the garden-hose level. Depending as it does on the principle of the open U-tube it is capable of producing fairly accurate results if manipulated with care. However, one of the greatest drawbacks to its use has been the difficulty of controlling the mobility of the water column. The present article deals with the use of a modification which overcomes this difficulty and which, as a result, may be relied upon to perform both rapidly and reasonably accurately. This instrument in its assembled form is shown in the accompanying sketch which is self-explanatory.

Calibration

The tube is filled with water until the meniscus shows in the gauge glass, care being taken that no air remains trapped within the water column. If the position of the meniscus is marked and then one of the poles is raised vertically a height of say 12 inches, the distance of travel of the meniscus to the new position will represent a change in elevation of 12 inches between the poles. This distance may then be used as the basis for the preparation of a scale to read in "inches of difference in elevation" both above and below a zero point representing "level elevation". This scale is affixed at the side of the gauge glass and so positioned that the zero mark is about midway of the latter thus enabling an equal range of changes in elevation to be read above and below zero or level elevation.

Adjustment of Zero in Level Elevation

Before readings can be taken, it is necessary to adjust the level of the meniscus to correspond with the zero mark on the scale when the two poles are standing on a level or horizontal base. This is done most conveniently by varying the length of the instrument pole by means of the sliding attachment.



GARDEN HOSE U-TUBE LEVEL

SOURCES OF ERROR

Accuracy of readings presupposes that no variation takes place in the volume of the water in the tube (length of the water column). In practice, however, variation does creep in from two major sources, namely spillage and dilatation or contraction of the water due to temperature changes. The former may be eliminated almost entirely by means of the control valve to be described in the next paragraph. With respect to the latter the surest way to keep errors (in readings) down to a minimum is to frequently check (and adjust if necessary) the zero elevation.

The Control Valve

For this instrument the type of valve needed is one which closes automatically. Thus, when in place at the end of the gauge glass, and undisturbed, it has the effect of considerably restricting the back and forth motion of the entire water column, and so its tendency to "jump" out of the tube when the latter is being moved about.

An ordinary motor car tyre valve adapted to fit the gauge glass was found to be very satisfactory. When a reading is to be made it is of course necessary to restore atmospheric pressure at this end of the U-tube, and this is done merely by opening the valve with a slight pressure on the pin head of the valve insert.

The mere presence of the valve, however, obviously does not render the instrument foolproof but a safe rule to follow in order to eliminate spillage is to manipulate the valve and instrument pole in such a way as "to keep the meniscus at all times within view" in the gauge glass.

If a motor car tyre valve is used it will be found necessary for more satisfactory operation, to modify it by filing or cutting away sufficient of the stem to allow the pinhead of the "insert" to protrude appreciably.

Operation—In use the instrument is first adjusted to zero or level elevation as mentioned before. It has been found most convenient for the instrument pole to "lead", in that its carrier (or operator) uses it to locate the unknown point, without the necessity of communicating with the carrier of the other pole.

The operations of plotting levels and graded contours are performed by this instrument simply and relatively rapidly. The location of vertical intervals for establishing the desired spacing of contour structures and for the determination of slope percentages is also made possible if suitable means are provided for increasing the length of the "long" pole.

The length of hose found most convenient was that which provided for a spacing between the poles, when fully extended, without stretching, of 25 feet.

Precautions to be taken in the Use of the Instrument

As already pointed out the greatest source of error lies in the variation in the volume and length of the water column. It is therefore essential for satisfactory results that the following precautions be taken :—

1. The water column in the hose should be bled free of entrapped air.
2. While the instrument is in use, the poles should be held *erect* and the connecting hose should not be lifted, but allowed to trail on the ground during changes in location of the poles.
3. The hose should be free from strains due to twisting, stretching or tight loops (kinks) while readings are being made.
4. All joints, as well as the valve, should be leak-proof.
5. The valve should never be opened during changes in location of the poles.
6. The meniscus should at all times, while the instrument is in use, be kept *within view* in the gauge glass.
7. The zero adjustment should be checked and, if necessary, adjusted at frequent intervals during operation.

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A NOTE ON SOME PROMISING TROPICAL LEGUME FORAGES

By

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Summary

A Propagation trial and the chemical composition of five promising legume forages are briefly discussed. It is concluded that the forage legumes should be propagated from seed treated with concentrated sulphuric acid for ten minutes wherever possible; the chemical analyses of all are favourable, especially that of the two *Indigofera* spp.

Introduction

Five promising forage legumes, *Indigofera endecaphylla*, *Indigofera subulata*, *Pueraria javanica*, *Centrosema pubescens* and *Calopogonium mucunoides* are being tried at the College. Except *Centrosema pubescens* which is an annual, all are perennials. In habit of growth *I. subulata* is semi-erect, whilst the others are creepers. Growth is good, and material is available for feeding both in the wet and dry seasons. These legumes all set viable seed. They are all palatable to stock, especially when fed in a mixture with grass. When fed to stock, no apparent ill-effects are observed. Yields are difficult to estimate, for when grown on any scale at the College, these legumes are usually grown in a mixture with grass.

Propagation

During August 1947, different types of planting material: stem cuttings, rooted sets and seed were compared on small observation plots on the College Farm.

Stem cuttings were planted two per "hole" and rooted sets one per "hole". A spacing of 2 ft. x ½ ft. was used.

Untreated and acid-treated legume seeds were sown in rows 2 feet apart and lightly covered with soil.

From observations on small plots during the wet season it was demonstrated that propagation of these legumes from seed is more successful than propagation by vegetative methods. It was also observed that seed treated just before planting with concentrated sulphuric acid for ten minutes, washed and air dried, gave a better, quicker and more even germination than those seeds which were untreated.

Nutritive Value

Legume forage samples were collected during the wet season of 1947 and 1948, and analysed by the Agricultural Department of the College. The following table shows part of the chemical composition of the five legume forages at different stages of growth.

Legume	Age (wks.) wet season	Composition as offered to Animals					Composition on a Moisture free Basis			
		Dry matter %	Crude protein %	Crude fibre %	CaO %	P_2O_5 %	Crude protein %	Crude fibre %	Ca %	P %
Indigofera endecaphylla	3	18.51	4.89	3.02	0.538	0.077	26.42	16.33	2.906	0.414
	6	17.03	4.16	2.77	0.540	0.064	24.43	16.24	3.168	0.378
	9	15.48	4.09	2.37	0.409	0.063	26.44	15.34	2.644	0.409
	12	19.91	4.36	3.57	0.069	0.069	21.91	17.93	2.460	0.346
Indigofera subulata	3	19.21	6.32	2.56	0.526	0.108	32.89	13.31	2.740	0.564
	6	18.60	5.14	2.59	0.698	0.084	27.64	13.93	3.750	0.453
	9	21.23	5.63	3.33	0.681	0.093	26.53	15.70	3.209	0.438
	12	22.75	5.83	3.26	0.730	0.089	25.62	14.32	3.210	0.391
Pueraria javanica (Tropical kudzu)	10	17.31	3.38	4.52	0.207	0.086	19.55	26.13	1.193	0.494
	15	23.55	4.06	6.97	0.368	0.092	17.26	29.60	1.564	0.392
	18	32.67	4.65	10.24	0.474	0.129	14.24	31.33	1.452	0.396
Centrosema pubescens	6	18.47	5.09	4.39	0.361	0.092	27.58	23.78	1.952	0.496
	9	20.19	5.17	5.49	0.337	0.111	25.63	27.18	1.670	0.550
	12	22.29	5.04	5.97	0.590	0.111	22.63	26.77	2.649	0.498
Calopogonium mucunoides	11	21.84	3.50	6.43	0.244	0.111	16.03	29.44	1.119	0.508

The chemical analysis of all, especially the two *Indigofera spp.* shows a high crude protein value at different stages of growth both on a moisture free basis and when offered as green feeding stuff to animals.

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